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LIFESAT

TRADE STUDY AND ANALYSIS SUMMARY REPORT

prepared for
GENERAL ELECTRIC
SUBCONTRACT VD 72001

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ACRONYMS AND ABBREVIATIONS

| | |
|--------------|---|
| AEM | Animal Enclosure Module |
| BPS | Bits per second |
| Btu | British thermal unit |
| C | Centigrade |
| CCD | Charge Coupled Device |
| CCF | Cold-Cathode Fluorescent |
| C.G. | Center of Gravity |
| CPU | Central Processing Unit |
| ECLS | Environmental Control and Life Support |
| ECLSS | Environmental Control and Life Support System |
| ECS | Environmental Control System |
| EKG | Electrocardiogram |
| EL | Electro-luminescent |
| ft | feet |
| g | gravity |
| GE | General Electric |
| gm | gram |
| Hg | mercury |
| hr | hour |
| Kcal | Kilocalorie |
| KSC | Kennedy Space Center |
| KwHr | Kilowatt hour |
| l | liter |
| lb | pound |
| I/O | Input/Output |
| LED | Light Emitting Diode |
| LMSC | Lockheed Missiles & Space Company, Inc. |
| mg | milligram |
| ml | milliliter |
| MTBF | Mean Time Between Failures |
| nm | nanometer |
| PM | Payload Module |
| ppm | parts per million |
| psi | pounds per square inch |
| RAHF | Research Animal Holding Facility |
| RFP | Request for Proposal |
| RM | Rodent Module |
| RRS | Reusable Reentry Satellite |
| SOW | Statement of Work |
| SRV | Satellite Recovery Vehicle |
| TBD | to be determined |
| uDACS | Microprocessr Controlled Data Acquisition System |
| RAM | Random Access Memory |

1.0 INTRODUCTION

This document presents a summary of LifeSat Rodent Module trade studies and analyses conducted to date by LMSC relative to the following topic areas:

- o Structural Analysis (Section 3.0)**
- o Environmental Control and Life Support (Section 4.0)**
- o Data and Electrical Power (Section 5.0)**
- o Habitat Design (Section 6.0)**

The completeness of these trade studies is consistent with the level of design and system definition. As such:

- o The Structural Analysis trade study is preliminary and only provides a direction of design. Further work is indicated in this area during the preliminary design phase.**
- o The Environmental Control and Life Support (ECLS) trade study is complete. This trade establishes the design approach for this system and only final layout and sizing is required.**
- o Analysis of the Data and Electrical Power is incomplete. A revised input is expected by February 1990.**
- o The Habitat Design trade study is complete. A major effort has been to develop layouts of modules which incorporate the direction set by other trades for from 6 to 24 rodents with mission durations of from 24 to 60 days. Some of the design approaches have been evaluated at the solid modeling level and some at the sketch level sufficient to only show feasibility.**

For reference purposes, the body of trade study and analysis summaries included in this document is preceded (in the section which follows) by a brief summary of the key LifeSat requirements governing rodent module design.

2.0 REQUIREMENTS SUMMARY

The requirements which are the prime drivers for the rodent module are summarized in this section. The data is gathered from the RFP and other applicable documents. The module specification presented in a companion document may be referred to for a more detailed compilation of requirements.

2.1 GENERAL REQUIREMENTS

The design shall accommodate 12 rats, 600 grams, for 24 days in orbit, caged individually or in groups (group size of up to six). Cages shall provide footholds for locomotion and access to food and water. Group cages shall be easily modifiable to allow inclusion of small compartments for mating, birthing, nursing, etc.

Each cage shall be designed to provide a uniform airflow and to prevent "dead air" spaces.

The waste collection system shall collect all wastes generated by the animals and prevent collected waste from reentering the cages. If chemicals are used in the waste collection process, they shall be prevented from contact with the animals during all phases of the mission.

Cage Dimensions: 70 sq. in. floor space x 7 in. high

2.2 FOOD REQUIREMENTS

Food shall be readily accessible to each rat on demand and shall be protected so it is not contaminated by rat waste products. The quantity of food provided for each rat shall depend on the energy value of the food. The food must have an energy value of at least 4 Kcal per gram. It shall be soft enough to allow rats to readily gnaw, but hard enough to prevent excessive growth of teeth unless an alternate substance for gnawing is provided.

Solid Food Consumed (4 Kcal/gm): 37.5 - 50 gm/day

2.3 WATER REQUIREMENTS

Potable water shall be readily accessible to each rat on demand. The water system shall prevent back contamination from the cages to the water supply. The water system shall provide at least two water dispensers in each cage and shall allow either dispenser to be disconnected from the water supply by a command. The amount of water provided for each rat shall be calculated from the amount of food provided according to the ratio of 1 ml/gm of food. The drinking water shall contain iodine in concentration no greater than 4 ppm, or chlorine in concentration no greater than TBD ppm.

Water Consumed: 40.5-54 ml/day

2.4 ENVIRONMENT REQUIREMENTS

Temperature:

During orbital flight, temperature shall be controlled to within +/- 2 degrees centigrade of any set point within the range of 18 to 26 degrees C. During Launch and recovery the temperature shall not exceed 30 degrees C for more than 0.5 hours and shall at no time exceed 35 degrees C.

Pressure: 14.0 to 15.9 psi

Humidity: 40% to 70%

Composition of Air:

| | |
|------|--|
| O2: | 18% to 22% |
| CO2: | less than or equal to 1.0% |
| N2: | present as required to maintain total pressure |

Air Flow:

Continuous air flow. Flow rate to be designed to maintain environment as described above and shall remain constant within a flight within +/- 5%. Maximum air speed is 240 ft/minute at any point within the cage.

Filtering:

Air entering the cages shall be filtered to remove particulates, contaminants, and microbes which might adversely affect the animals.

| <u>Constituent</u> | <u>Maximum Allowable Amount</u> |
|--------------------|---------------------------------|
| CO ₂ | 1% partial pressure |
| CO | 50 ppm |
| NH ₃ | 25 ppm |
| H ₂ S | 20 ppm |
| CH ₄ | 0.25% |

Lighting:

Illumination level and light/dark cycle shall be the same for all cages. All illumination on surfaces visible to the animals shall be diffuse.

3.0 to 3.7 footcandles in each cage. Light measured in the middle of the cage with no animal present. The light intensity on any surface visible to an animal shall not vary by more than 10% during a flight.

Spectrum shall be same as natural light.

The durations of the light and dark portions of the cycle shall be separately selectable in 30 minute increments within the range of 0 minutes to 15 hours with an accuracy of +/- 1 minute. The total duration of a complete light/dark cycle shall be selectable in 30 minute increments with the range of 0 minutes to 30 hours.

2.5 RAT DESIGN VALUES

| <u>Parameter</u> | <u>Design Value</u> |
|---------------------|---------------------|
| Maximum Rat Weight | 600 gm |
| Solid Food Consumed | 37.5 - 50 gm/day |
| Water Consumed | 40.5 - 54 ml/day |
| Oxygen Consumed | 14.175 l/day |

| <u>Parameter (cont'd)</u> | <u>Design Value (cont'd)</u> |
|----------------------------|------------------------------|
| Feces Produced (60% water) | 18.75 gm/day |
| Urine Produced | 20.25 ml/day |
| Metabolic Heat | 150 Kcal/day |
| Respiratory Water | TBD |
| C02 Produced | 14.175 l/day |
| CH4 Produced | 6.6 mg/day |

3.0 STRUCTURAL ANALYSIS

During the trade study phase of this effort, structural analysis was restricted to:

- o The design of the End Cones (Section 3.1)
- o Access Hatch vs End Plate Removal (Section 3.2)
- o Number of Attachment Point/Locations (Section 3.3)
- o Late Access Considerations (Section 3.4)

Analysis of each of these areas will be considerably expanded during the preliminary design phase.

3.1 END CONE DESIGN

A structural analysis of the LifeSat end cones was carried out. Two options were studied for the basic design of the pressurized module: 1) a flat end plate stiffened by the use of honeycomb panel, and 2) a series of semi-elliptical thin shelled end plates with various heights. Additional analyses will be performed during the preliminary design phase. The basis for this analysis was as follows:

- 1) The LifeSat Payload Canister was rough-sized for a number of head configurations to support trade studies involving Number-or-Rodents versus Time-in-Orbit.
- 2) Elliptical domed heads of various depths and flat honeycomb sandwich panel heads were investigated for 6061-T6 aluminum and 6A1-4V titanium materials.
- 3) Summary charts of Canister Weight versus Diameter and Volume versus Diameter for various configurations of elliptical and honeycomb panel heads are attached. A constant Canister length of 36 inches was assumed for these studies.

3.1.1 Discussion

As shown in Figure 3.1-1, the volume lost due to the honeycomb is approximately the same as that lost to rounded corners of a 6" high elliptical end plate. The primary difference is weight, as shown in Figure 3.1-2. Although the design of the cylindrical middle section is the same in the two approaches, the elliptical end plates are significantly lighter.

Access hatches for installing or removing habitats are significantly easier to engineer into a flat honeycomb panel than the complex 3-D contours of the elliptical end plates. However, it has been determined that small access hatches will not be required (see Section 3.2 for details).

In comparing materials, aluminum was approximately 30% lighter than titanium due primarily to considerations of minimum gage requirements, the latter being more resistant to dings and scratches, and therefore more durable for frequent reuse.

3.1.2 Conclusion

On the basis of weight, it is recommended that at least a 6" high elliptical end cap be used for the smaller sized payload canisters (approximately 44" diameter), and 8" high elliptical end caps be used for larger sizes.

Aluminum is the recommended material.

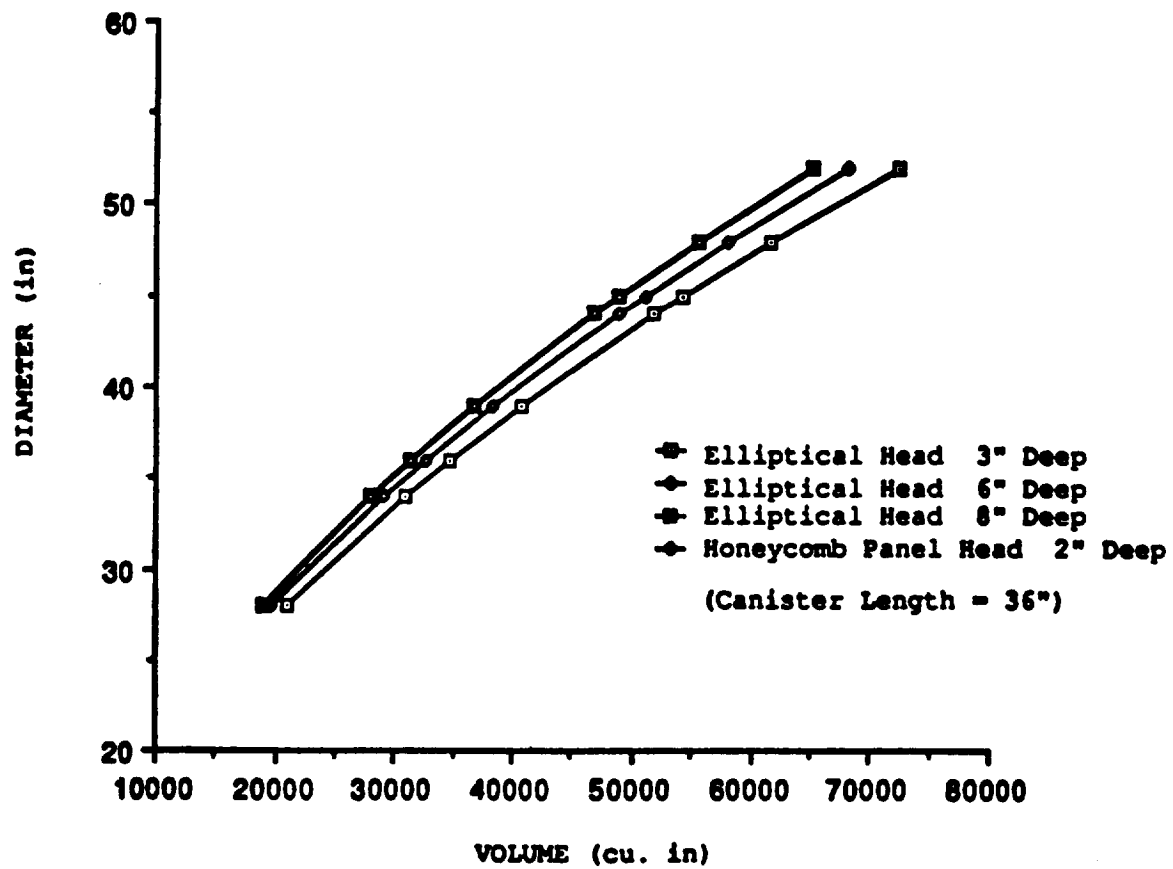


Figure 3.1-1 Canister Volume vs. Diameter

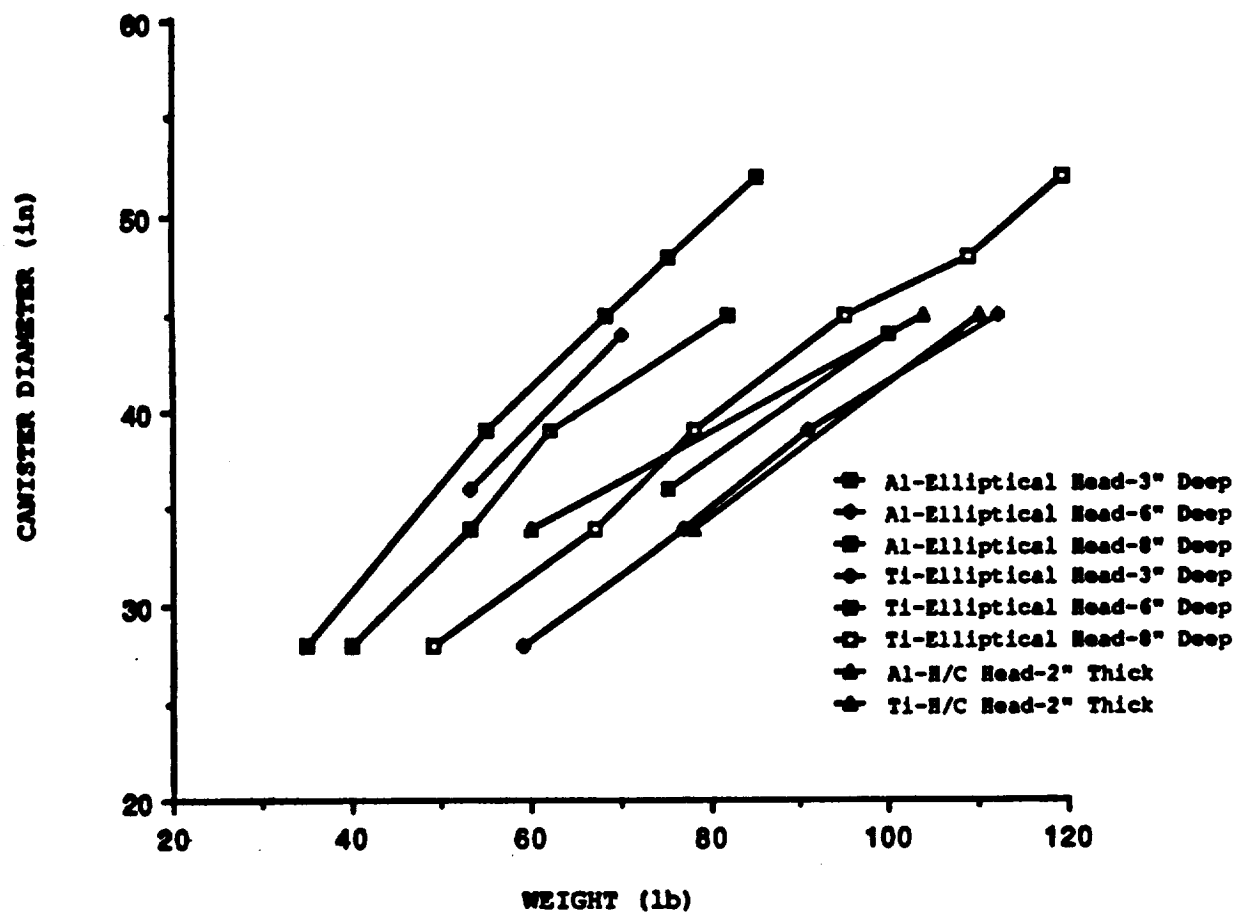


Figure 3.1-2 Canister Weight vs. Diameter

3.2 ACCESS HATCH VS. END PLATE REMOVAL

3.2.1 Discussion

The following assumptions were made in the performance of this trade study:

- o Canister head weight is less than 50 lb.
- o Total canister weight is less than 550 lb.
- o Approximately 28 bolts attach canister head to cylinder.
- o Approximately 8 bolts attach canister to vehicle.
- o Access hatch configuration will require head or cylinder reinforcements, seals, and bolts.
- o Relatively large access hatch (or hatches) are required to permit insertion of rodent cages.
- o Smaller hatch required if rodents are inserted separately.
- o Either access hatch or head removal configuration will require removal of Reentry Vehicle hatch or heat shield.

3.2.2 Conclusion

Based upon the results of this trade study, the following recommendations are suggested:

- o Insert rodents and rodent cages with canister head removed.
- o Consider the use of external umbilical lines for air and cooling prior to launch and during ground recovery before rodent removal.

3.3 NUMBER OF ATTACHMENT POINTS/LOCATION

The details of the structural interfaces between the payload module and the reentry vehicle are best determined later in the preliminary design phase. However, since this area affects the thermal analysis, a preliminary analysis was performed. The key problem is the thermal soak-through from reentry heating that occurs during the

terminal parachute decent and the post-landing period until auxiliary cooling can be provided. At this point in the mission, the RM radiator (i.e., the reentry body heat shield) is no longer available for heat rejection and is, in fact, the source of the heat load.

3.3.1 Discussion

In order to minimize thermal contact with the re-entry vehicle, a minimum number of mounting points is desired. It was decided to use a kinematic mounting scheme consisting of 3 flanges equally spaced around the periphery of the cylindrical portion of the RM, co-planar with the RM's center of gravity (C.G.) These mounts primarily handle the axial loads during launch and reentry and landing. Lateral loads would create a moment (assuming the C.G. of the RM is not exactly co-planar with the 3 module side mounts) and this requires a fourth mount located at the end of the RM.

3.3.2 Conclusion

A kinematic mounting system comprised of three "equatorial" attach points spaced 120° apart approximately co-planar with the C.G., plus a fourth located on the module's aft end has been chosen as the preliminary baseline. This decision will be revisited during the preliminary design phase as new information becomes available.

3.4 LATE ACCESS

These two trade studies are highly related and have been combined into a single trade. The basic issue concerns how the specimens are installed in the reentry vehicle just before launch and removed as quickly as possible after landing. In the case of rodents, post-landing access is more important than pre-launch, for two main reasons. The first is that the quality of science will not be affected by the animals sitting peacefully in their cages on the pad awaiting launch, whereas the re-adaptation process begins immediately after return to a gravity field. Thus the science starts to degrade from the moment of reentry. The second reason has to do with post-landing environmental (particularly temperature) control. It is difficult to control temperature

inside the payload module for long periods of time without access a heat rejection system. It is therefore of paramount importance to remove the animals before the payload module overheats in the hot desert sun.

3.4.1 Discussion

The foregoing rationale was used to determine how the specimens are accessed. Three options have been investigated: 1) removing the entire payload module, 2) removal of habitats, and 3) removal of the individual rodent cages. In order to ensure good science, it is imperative that the specimen environment be kept constant until the rodents are delivered to the laboratory for analysis. The ECLSS must therefore remain operating. The same applies to the RM's thermal insulation. In short, much (if not most) of the RM must accompany the specimens to the laboratory. This obviates the latter two options.

The scenario envisaged for early post-landing access is to equip the ground support vehicles with a portable heat sink which would, upon arrival at the reentry vehicle, be connected to the RM to stabilize temperatures. This would give ground crews the additional time to remove the module (or at least the portion of it that contains the habitats and ECS.) Removal of this large item would obviate the need for smaller access hatches in the end plates.

3.4.2 Conclusion

It is therefore recommended that access be provided by removing, if not the whole RM, that portion of the RM that includes the habitats and ECS. This obviates the need for small access hatches in the end plates.

4.0 ENVIRONMENTAL CONTROL AND LIFE SUPPORT (ECLS)

The environmental control system provides a habitat environment for the rodents in the module. This system is composed of the following functional elements:

- o Atmosphere Supply (Section 4.2)
- o Carbon Dioxide Removal (Section 4.3)
- o Trace Contaminant Control (Section 4.4)
- o Humidity Control (Section 4.5)
- o Temperature Control (Section 4.6)

It is the purpose of this trade study to select recommended approaches for each of these functional areas. In some cases methods of approach to providing a function can be directly compared. In others, several functions must be combined to identify the optimum approach. In this section the process for selection of the recommended approach to developing the environmental control system will be presented.

4.1 GENERAL

In the comparative analysis, the key parameters considered included:

- o Power consumption
- o Development status
- o Cost
- o Weight
- o Volume
- o Qualitatives

Of these parameters, power consumption turned out to be a major driver in the environmental control process selection. Referring to the Phase A Study, a power system weight of 167 kg is required to supply 45 KwHr of energy. This is 8.2 lb per KwHr, which was used in this study for the purposes of converting energy requirement differences to effective weight differences. Even if this penalty for power could be reduced by a factor of 2, power will remain a major driver in many of the trades.

4.2 ATMOSPHERE SUPPLY

Oxygen and nitrogen must be supplied to provide make-up for oxygen consumed by the animals and losses associated with seal leakage, as well as losses resulting from vacuum regeneration carbon dioxide and water control, if such systems are used. The methods of atmosphere supply (oxygen and nitrogen) which were considered included:

- o for oxygen storage:
 - High pressure gas
 - Cryogenic
 - Superoxide chemical
- o for nitrogen storage:
 - High pressure gas
 - Cryogenic

4.2.1 Storage Quantities

The storage quantities for atmosphere gases are calculated from the metabolic consumed oxygen and losses through seals and vacuum regenerative systems, if any. These are calculated as follows:

Metabolic oxygen

The requirements set the oxygen consumed at 14.175 liters/rodent day. This corresponds to 0.04167 lb/rodent day.

Seal leakage

Data on the leakage of an O-ring seal for the payload module shows 2.85×10^{-5} lbs gas/day/inch of seal.

For a module 44 inches in diameter with circumferential seals at one end, this results in a leakage of 0.24 lbs in 30 days. Leakage is considered to be 22% oxygen and 78% nitrogen by weight.

Process Vacuum Regeneration

If a vacuum desorbed solid amine or molecular sieve system is selected, there will be losses due to ullage and adsorbed gasses. For a 12 rodent system these losses will amount to 0.136 and 0.17 lb/day for the respective systems.

In summary, oxygen storage is set by metabolic consumption with an ullage contribution as required. Leakage is a second order effect and for all practical considerations can be neglected for oxygen storage. Oxygen losses due to the use of vacuum regenerated systems will constitute at most 25% with a more likely level of 6%.

Nitrogen storage required due to leakage is a fraction of a pound. Nitrogen losses due to the use of vacuum regenerated systems will constitute the major portion of the nitrogen storage. Nitrogen storage, even with losses, will likely be less than 3.25 lbs for a 30 day mission.

4.2.2 Oxygen Storage

For a typical 30 day mission with 12 rodents, the metabolic oxygen amounts to 15 lbs with leakage at less than 0.1 lb. At this level leakage can be neglected.

Gas Storage

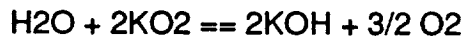
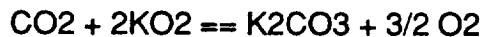
Data from Hamilton Standard and Allied-Signal indicates that the weight of high pressure gas storage tanks at 0.7 lb of tank per lb of oxygen using carbon filament wound Kevlar technology. Tanks of this type are developed and being produced in a variety of sizes.

Cryogenic Storage

Cryogenic tanks can be produced for less than 0.3 lb tank/lb oxygen. In operation, these tanks use electrical energy to maintain pressure during the early stages of expulsion. This power will average out at about 30 Btu/lb or 0.07 lbs for power per lb of oxygen. The cryogenic tanks require temperature and pressure control, are more complex and costly, are probably less survivable on recovery, and require special ground support for prelaunch filling. The ancillary equipment for the cryogenic system, heat exchangers, valves, controls, etc., will add another 2 lbs weight. An additional disadvantage of the cryogenic approach is the ground support required for prelaunch filling which adds both complexity and cost.

Superoxide Systems

In a superoxide system carbon dioxide and water react with potassium superoxide as follows:



These reactions show a production of molecular oxygen at 1.5 times the carbon dioxide removal rate and also reaction with water vapor. Also note that the production of oxygen through the humidity reaction could lead to a shortfall in oxygen at the end of the mission. Prevention of this requires careful control of bed temperature and inlet humidity level.

Evaluation of the superoxide system must include credits for carbon dioxide control. For each liter of carbon dioxide removed, 1.5 liters of oxygen are produced. As the carbon dioxide produced and oxygen produced (per the requirements) are in balance at 14.175 liters/rodent day, superoxide systems will produce a 50% excess of generated oxygen. Considering the low seal leakage, the excess must be dumped to prevent pressure buildup. This will result in the loss of considerable nitrogen. For each

lb of oxygen required, 0.5 lb of oxygen are wasted along with 1.8 lb of nitrogen. The control of superoxide systems is very difficult because the KO₂ chemical reacts with water vapor (humidity water) as well as carbon dioxide. There is a tendency to overproduce at the start of the mission due to the reaction with water vapor. The excess oxygen supply can be eliminated by use of a composite bed composed of both the superoxide chemical and lithium hydroxide. This adds complexity and, as will be seen in system level trades, is still not optimum.

Selection

High pressure gas storage is recommended for the atmospheric oxygen and nitrogen. It carries an intermediate weight penalty but has the advantage of lower complexity and cost over cryogenic systems at a penalty of about 0.3 lb/lb stored oxygen or 4.5 lb for the 30 day, 12 rodent mission.

4.3 CARBON DIOXIDE REMOVAL

The following methods of carbon dioxide removal were considered:

- o Adsorption by molecular sieve, including vacuum regeneration
- o Adsorption by solid amine, including vacuum regeneration
- o Adsorption by lithium hydroxide
- o Adsorption by potassium superoxide.

Of these methods the molecular sieve and solid amine systems can be directly compared at the functional level. The lithium hydroxide, superoxide, and selected vacuum regeneration system must be compared at a higher system level due to interaction with the functions of oxygen production with superoxide chemisorption and humidity water control with the vacuum regeneration systems.

Data on the molecular sieve and solid amine systems was supplied by Allied-Signal and Hamilton Standard, respectively. The molecular sieve optimization is described in a separate Allied-Signal report. The solid amine data was received by phone from Hamilton Standard and is a point design for 12 rodents.

4.3.1 Molecular Sieve

A molecular sieve system was developed and successfully operated in the Skylab program. The process uses a zeolite sorbent which, when exposed to the cabin air, adsorbs both carbon dioxide and water vapor. The bed can then be regenerated by exposure to a vacuum of less than 10^{-5} atmospheres. The LifeSat would use two beds, one adsorbing while the other is being desorbed.

An Allied-Signal optimization of the molecular sieve system led to the selection of a two bed thermal swing cycle. The key parameters of this system are presented in the summary table below. The thermal swing cycle is more complex than the Skylab system and has some development problems. The selection of the thermal swing cycle is driven by far higher atmospheric loss penalties associated with the adiabatic cycle (1.03 lb/day including tankage for 12 rats).

4.3.2 Solid Amine

A solid amine system is currently under development for use on the extended Shuttle program. Prototypes have been built for spacesuit and Space Station programs. The development risk is therefore considered low even though flight hardware has not, as yet, been qualified. Its operation is identical to that of the molecular sieve system. A major operational difference is that it does not adsorb oxygen or nitrogen. Thus, atmospheric losses are less than that of the molecular sieve system. Furthermore, vacuum desorption can take place at a pressure as high as 1 mm Hg. The key parameters of this system are presented in the following summary table:

| <u>Parameter</u> | <u>Molecular Sieve</u> | <u>Solid Amine</u> |
|------------------|------------------------|--------------------|
| System weight | 8.5 lbs | 10 lbs |
| Air ullage | 0.17 lbs | 0.136 lbs |
| Half cycle | 6 minutes | 30 minutes |

The recommendation of the solid amine system over the molecular sieve system is based upon the lower air loss penalty and higher regeneration pressure, along with its lower complexity.

4.3.3 Lithium Hydroxide

Lithium hydroxide removal of carbon dioxide has been used on several spacecraft as well as in the spacesuits. It removes carbon dioxide according to the following reaction:



This method is of low risk and is the lowest in cost. However, it must be coupled with a condensing heat exchanger/water separator humidity control system.

4.3.4 Potassium Superoxide

The reactions for this type of system are outlined in the section on oxygen supply. Systems have been built for breathers and submersible systems, and non-US spacecraft. This system must also be coupled with a condensing heat exchanger/water separator humidity control system.

4.3.5 Prelaunch and Recovery Considerations

If a vacuum desorbed system for carbon dioxide and humidity control is selected, operations within the Earth's atmosphere will require supplemental control. A small lithium hydroxide and desiccant bed must be provided to allow control during these mission phases.

For prelaunch operations, cold air can likely be made available at a low cost. Flushing cold air through the rodent module will provide all life support functions - including humidity control, carbon dioxide removal, and atmosphere supply. The only module

impact will be to provide the necessary interfaces and shutoff valves. This would leave only ground recovery operations as a problem area. If a hot desert landing is assumed, the ambient will be too hot for use of a flush flow system, and closed operation with a supplemental coolant seems in order. The launch and reentry periods are sufficiently short that the vehicle capacity will absorb the transients.

4.3.6 Summary

Based purely on carbon dioxide removal, lithium hydroxide might be selected based on simplicity and low cost even though it carries a weight penalty on the longer missions (crossover with solid amine is about 10 days). However, when humidity control constraints and oxygen supply are included, the solid amine is the favored system. This is discussed in later sections.

4.4 TRACE CONTAMINANT CONTROL

Trace contaminants will be given off by the animals and the waste management system. The method of choice for control on spacecraft is the use of activated carbon. Research Animal Holding Facility (RAHF) work at LMSC has shown that the breakdown of metabolic waste is inhibited by treating collection system surfaces with urea stabilizers. The key contaminants expected are ammonia, carbon monoxide, and methane along with lesser amounts of a wide range of organic compounds.

The ammonia is controlled by adsorption on base treated activated carbon. Adsorption is enhanced by the addition of treatment with phosphoric acid. The carbon maintains its capacity for the organic contaminants with the acid treatment. The carbon monoxide is removed by the addition of platinum on carbon in the carbon bed. Methane is difficult to oxidize without a power-consuming high temperature oxidizer and thus must be controlled by venting a small portion of the atmosphere. This results in an atmospheric tankage penalty.

Lockheed experience with a regenerable trace contaminant control system has shown that activated carbon can be regenerated using the space vacuum. The inclusion of a carbon section at the outlet end of a vacuum desorbed CO₂ system will provide trace

contaminant control with a minimum penalty. The carbon will be regenerated and the methane controlled by the system losses. Carbon monoxide will be controlled by a small bed slice of platinum treated carbon.

Molecular sieve for carbon dioxide removal is usually run dry and thus does not normally remove ammonia. However, on the LifeSat its use would also remove water. Under this operating condition, the water and carbon dioxide adsorbed will provide a moist and slightly acid environment which is favorable to ammonia control.

The selection of a solid amine sorbent is less likely to provide ammonia control. Thus a treated activated carbon section of the adsorber will be required.

4.5 HUMIDITY CONTROL

Water vapor is put into the air by both the respiration of the animals and also the evaporation of water from the waste management system. This water must be removed to maintain the humidity level. Two methods of water removal were compared. These methods are:

- o Condensation in a low temperature heat exchanger
- o Adsorption in a sorbent bed.

4.5.1 Condensation

This method is used in most manned spacecraft systems. Humid air is passed through a heat exchanger and cooled to below its dew point. The water is condensed out. The resultant air and liquid water stream then passes through a water separator with the air being returned and the water transferred to storage or vented overboard. Development efforts on small water separators have resulted in units which consume from 30 to 50 watts. The 30 watt Hamilton Standard unit is in its design phase while the 50 unit RAHF separator has been flight qualified. Considering a conservative power draw of 40 watts, the separator power penalty is 7/9 lb/day for a 12 rodent size unit. With a fixed weight of 2 lbs for the heat exchanger and 8 lbs for the fan/water separator, it is seen that power penalty is the dominant trade factor.

Alternate methods of water separation may be possible. These include the use of a wick to remove water from the heat exchanger. This approach would require water transfer hardware and either waste water storage or vacuum dump capability. This could reduce condensing system power penalties to the level of adsorption systems. However, combined system penalties would still be lower with the adsorption approach. Therefore, these techniques (similar to those used in the Apollo program) were not investigated further.

4.5.2 Absorption

Both the molecular sieve and solid amine carbon dioxide removal systems also remove water. The designs compared in the above section are based on removal of both water and carbon dioxide. The water absorbed is discharged to space during the regeneration portion of the cycle. This approach eliminates the need for an air/water separator. It does require a fan for air circulation, and a heat exchanger (smaller than the condenser discussed above) to provide thermal control. This system can be made to operate with a fan having a power of 8 watts. The resultant power penalty is 1.6 lb/day for a 12 rodent system.

4.5.3 Results

The savings in power with the adsorption approach (equivalent to 6.3 lb/day) results in its recommendation. If vacuum dumps are not permissible, a passive approach (such as the use of wicks) should be investigated for heat exchanger water removal to limit system power.

4.5.4 System Level Comparisons

Because some of the approaches to some of the functions cross boundaries, a system level comparison which shows the total penalty of all common functions is presented in this section.

The analysis has been carried out for a 12-rat vehicle with a 30 day mission. As the number of animals and the mission duration varies, items in the weight summary table will vary differently.

Table 4.5-A
System Level Comparison Trade Table

| <u>Approach</u> | <u>LiOH</u> | <u>SA</u> | <u>KO2</u> | <u>KO2/LiOH</u> |
|---|-------------|-----------|------------|-----------------|
| FAN POWER | 40 watts | 8 watts | 40 watts | 8 watts |
| POWER PENALTY | 236 lbs | 47 lbs | 236 lbs | 236 lbs |
| linear with mission time and exp .5 with animals | | | | |
| FAN/WS WEIGHT | 10 | 5 | 10 | 10 |
| exp .5 with animals | | | | |
| HX WEIGHT | 2 | 1 | 2 | 4 |
| linear with animals | | | | |
| CO2 REMOVAL WT | 29 | 10 | 86 | 67 |
| LiOH linear with animals & mission time | | | | |
| SA exp .8 with animals | | | | |
| O2 WEIGHT | 15 | 15 | 0 | 0 |
| linear with animals and mission time | | | | |
| O2 TANK WEIGHT | 11 | 11 | 0 | 0 |
| linear with O2 weight | | | | |
| ATMOSPHERIC LOSS QTY | 0 | 4 | 0 | 0 |
| linear with mission time and animals | | | | |
| ATMOSPHERIC LOSS TANK WT | 0 | 3 | 0 | 0 |
| linear with ullage | | | | |
| TOTAL WEIGHT PENALTY | 303 | 96 | 334 | 317 |

NOTES:

- o Power penalty of 8.2 lbs/KwHr
- o 12 rodents
- o 30 day mission
- o Tankage penalty
- o 0.7 lb tank/lb fluid
- o SA can accommodate varying animals with cycle time change and alteration in ullage supply

4.6 THERMAL CONTROL

During the periods of time between specimen loading into the Payload Module (PM) and orbital insertion, and between reentry and specimen removal, the PM ECLSS must provide temperature control without access to an external heat sink.

4.6.1 Discussion

Several types of internal heat sinks can be utilized during these periods including a hybrid approach that utilizes different heat sinks for different purposes. The approaches studied are:

- o Wax packs to absorb the reentry soak-through heat, located at the structural interfaces between the reentry vehicle and the PM
- o A flash evaporator on the vehicle coolant loop to provide a substitute heat sink during reentry and post-landing
- o Freezing one or more of the water tanks before launch and using this as a heat sink for the main vehicle coolant loop during prelaunch and ascent phases.

In order to evaluate these options, a prelaunch-orbit period of 12 hr and a reentry-to-recovery period of 3 hr was assumed. The heat load from the baseline 12 rodents + subsystems is approximately 50 watts.

The sublimator option is currently being used by the Space Shuttle to reject heat when the radiators are stowed, and for supplementing the radiator panels during peak loads. Two types are used: 1) a water flash evaporator used for altitudes above 40-50,000 ft, and 2) an ammonia boiler for altitudes below this. Since most of the time the boiler would be used at sea level, an ammonia boiler is the obvious choice for this type of heat sink. However, ammonia venting in the vicinity of the vehicle during animal insertion and post-landing recovery operations is most undesirable. This suggests

less optimum heat transfer fluids which are less toxic. The table below shows the relative merits of some candidate fluids.

| <u>FLUID</u> | <u>ENERGY</u> | <u>COMMENTS</u> |
|----------------|---------------|--|
| Water | 2478 Kj/kg | High altitude only |
| Ammonia | 1226 | Proven but toxic |
| Freon | 146 | Higher weight than NH ₃ /less toxic |
| Carbon dioxide | | Difficult design/sublimates |

Using the 3 hour recovery time, approximately 214 gm of water (assuming a wick type evaporator), 433 g of ammonia, or 3.64 gm of freon 12 would be required. Since the water evaporator would require 2 separate designs, its use will be more costly and complex and is not recommended.

For the prelaunch operations, a ground-provided cooling loop of flush flow using cooled air is preferred. If this is not available, then an evaporative unit is indicated. Alternatively, one of the water tanks could be frozen as a heat sink. Approximately 6.4 kg of ice would be required for the 12 hour prelaunch period. This represents only 36% of the baseline 12 rodent, 30 day supply.

4.6.2 Recommended System Schematic

The results of the trade studies to select approaches to providing each of the environmental control functional requirements leads to the schematic shown in Figure 4.6-1.

In this system, both the oxygen and nitrogen are supplied from high pressure tanks. Filament wound carbon fiber/Kevlar 5000 psi tanks provide a low volume without having an excessive penalty associated with the gas compressibility factor. A control system which provides oxygen on demand of partial pressure sensors with nitrogen on an as required basis to maintain total pressure is recommended. In this system oxygen is always the priority feed gas, with nitrogen only fed when oxygen is at its high cutoff level.

A solid amine vacuum regenerated system is recommended for both carbon dioxide and humidity control. This approach, which eliminates the need for a high power consumption water separator, provides the lowest penalty. A molecular sieve is an alternate but has a higher penalty associated with sorbed atmospheric gases which are dumped to space during regeneration. Either system used activated carbon in the bed for control of trace contaminants. The carbon is also regenerated by exposure to space vacuum. A key to making this system work effectively is the design of a low thrust vacuum discharge to main the desired "g" level.

The solid amine system will maintain the habitat dew point below the coolant temperature. Thus, the thermal control heat exchanger will not run wet. The removal of animal sensible load and electrical load due to lighting, fans, and controls constitutes the thermal load. The flow in the ECLS loop is set by this load and heat exchanger temperature constraints.

Bladder water tanks are a low cost, low weight and volume approach to storage which was proven in the Research Animal Holding Facility (RAHF). The use of the more costly, higher isolation metal bellows tanks is not warranted.

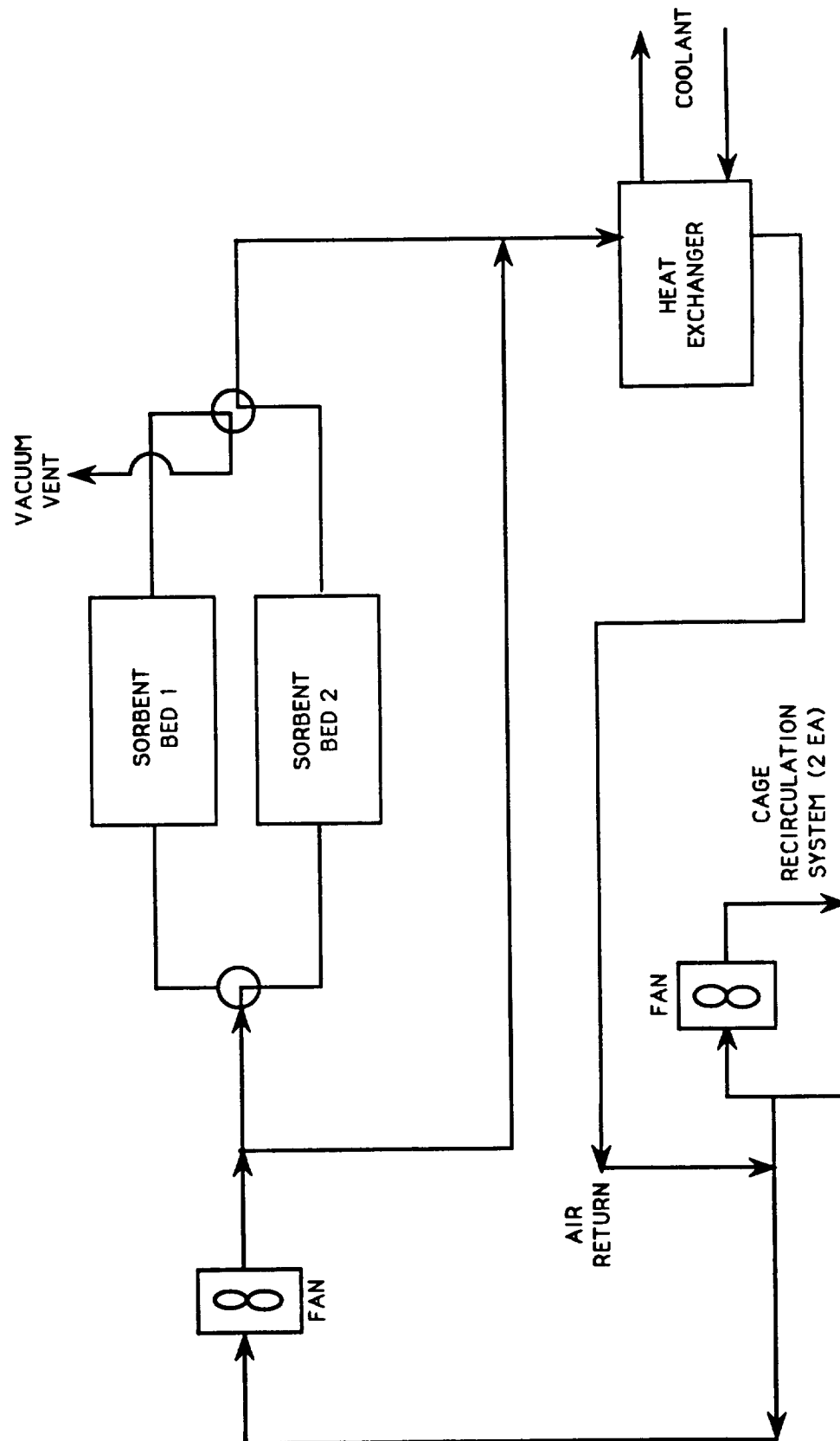


Figure 4.6-1 Environmental Control and Life Support Schematic

5.0 DATA AND ELECTRICAL POWER

This section contains a description of the Data and Electrical System concepts and a summary of the following tradeoffs:

- o Physiological Data Downlink vs. On-Orbit Recording/Downlink (Section 5.2.1)
- o Video Downlink vs. Frame Storage and Downlink (Section 5.2.5)
- o Location of the Mass Storage Device: Inside vs. Outside the Payload Module (Section 5.2.3)
- o Commonality in the PM and SRV Microcontroller vs. Customized Controllers for Each (Section 5.2.4)
- o Location of the Power Switching Relays: Inside vs. Outside the Payload Module (Section 5.2.5)

5.1 GENERAL

5.1.1 Payload Module Data System

The Payload Module (PM) is a sealed vessel that will provide life support and experiment support for 6 to 24 rats. A Payload Module data system is required to manage the payload environment and provide engineering and scientific data to mission controllers and scientists on the ground.

5.1.2 Data System Functions

During a typical mission, the Payload Module data system must perform the following functions:

1. Manage the Environmental Control and Life Support (ECLS) system. This includes acquiring data from ECLS sensors, processing the data, and controlling effectors.
2. Acquire physiological data from the experimental specimens.
3. Acquire non-physiological scientific data (e.g., food and water consumption).

4. Acquire video images of each specimen.
5. Time stamp and source tag all acquired data.
6. Manage the saving of data in mass storage.
7. Implement the protocol required to communicate with the Reusable Reentry Satellite (RRS) control system. Transmit data to the RRS control system or uplink commands as appropriate.
8. Execute commands uplinked from the RRS control system or the ground command center.

5.1.3 PM Data System Concept

The PM Data System architecture will be compatible with the architecture of the RRS Vehicle Data System. A microprocessor-based data acquisition and control system (uDACS) is the preferred approach at this time. This is also the approach favored for the RRS Vehicle Control System. The uDACS approach offers implementation of a data system in a compact, lightweight, and power efficient unit offering data and command handling, redundancy, and radiation hardness. The system will communicate with the RRS Data System via a redundant serial data link (e.g., MIL-STD 1553). Data acquisition will be performed by standard plug-in Input/Output (I/O) cards. Standard cards required include a 12 bit analog input card, a discrete I/O card, and a relay driver card. In addition to these standard I/O cards, a video image processing card, and a 640K X 16 static Random Access Memory (RAM) card will be required to store captured video frames between downlink windows.

In addition to the uDACS controller, additional signal conditioning hardware will be contained in the ECLS, Video, and Physiological Telemetry systems. The ECLS system will contain the following sensors and effectors:

| ITEM | QUANTITY IN PM | DATA INTERFACE |
|-------------------|----------------|----------------|
| ECLS Fan | 1 | Relay output |
| Recirculation Fan | 2 | Relay output |
| Latching Valves | 11 | Relay output |
| Humidity Sensor | 2 | Analog input |
| O2 Sensor | 2 | Analog input |
| Pressure Sensor | 2 | Analog input |

Video hardware may include from 6 to 24 miniature low power Charge Coupled Device (CCD) cameras, a camera switching unit, a camera control unit, and a videoencoder unit.

Telemetry transmitters implanted in rats may transmit up to 5 multiplexed physiological signals. The PM must include hardware for receiving, demodulating, demultiplexing, and conditioning the physiological signals.

Figure 5.1-1 shows a block diagram of the PM Data System Concept.

5.2 DATA AND ELECTRICAL POWER TRADE SUMMARY

5.2.1 Physiological Data Downlink vs. On-Orbit Recording/Downlink

The PM uDACS will support multichannel implanted telemetry. For each of 6 to 24 specimens, there may be up to 5 channels of physiological data consisting of 1 Electrocardiogram (EKG) quality channel (0-100 Hz bandwidth), and 4 low bandwidth channels (1 Hz or lower). A minimum of 8 bits analog to digital data conversion resolution will be required for each telemetry channel.

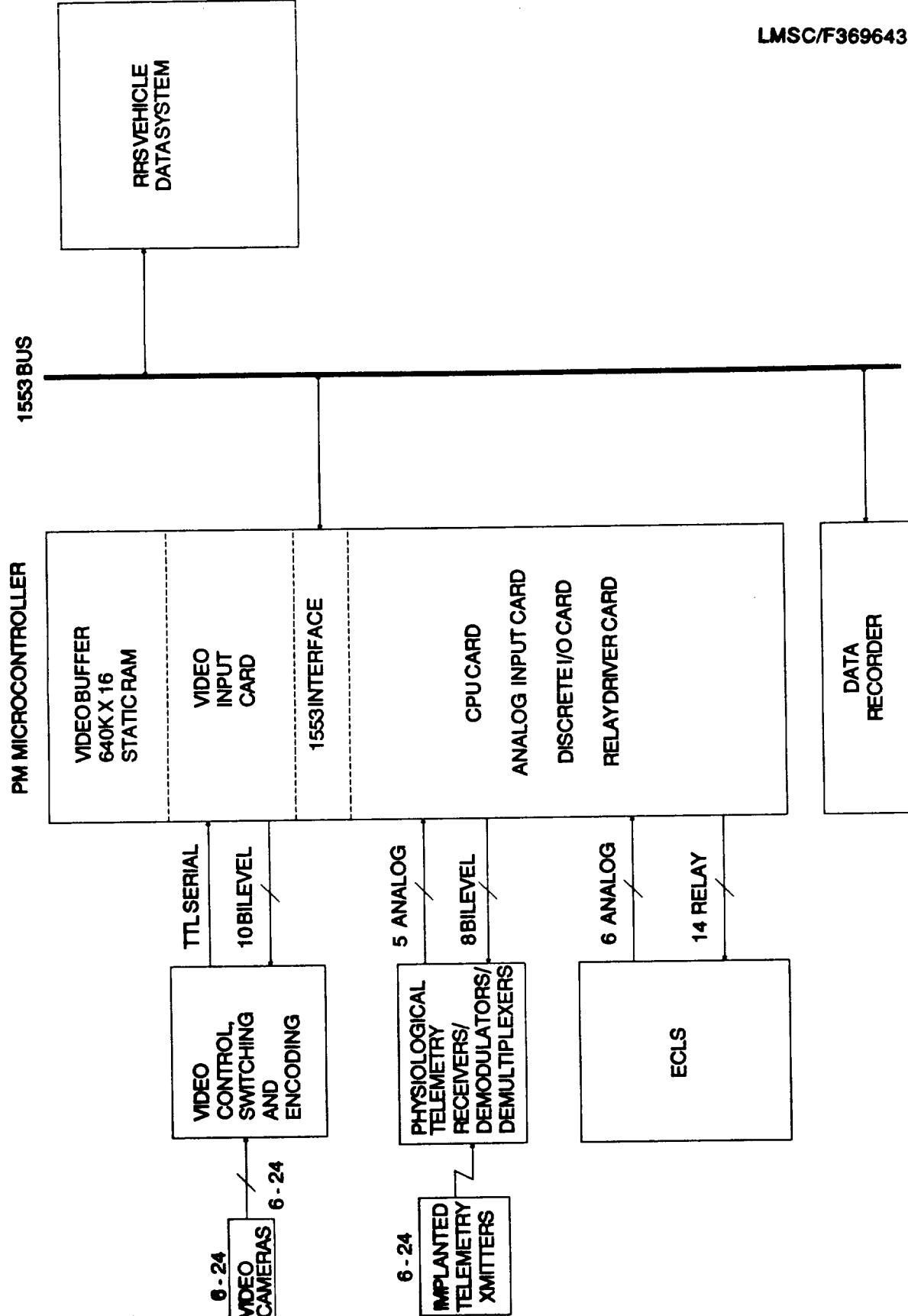


Figure 5.1-1 Data and Electrical Power Trade Summary

During each downlink communications window, the PM Data System should transmit, at minimum, a core status data package to the RRS Data System for transmission to the ground. The contents of a likely core data package are listed below:

| CORE DATA | SAMPLES | SIZE/SAMPLE | TOTAL SIZE |
|----------------------------|-----------|---------------|-----------------|
| PM Temperature | 2 | 8 Bits | 16 Bits |
| PM Pressure | 2 | 8 Bits | 16 Bits |
| Relative Humidity | 2 | 8 Bits | 16 Bits |
| <u>Specimen Heart Rate</u> | <u>24</u> | <u>8 Bits</u> | <u>192 Bits</u> |
| Total Core Raw Data | | | 240 Bits |

The 240 bit core data total does not include any data identification overhead which will include time tagging and source labeling. This may add an additional 4 to 5 bytes (8 bits each) per data sample bringing the total core data package to about 1200 bits. Additional communications overhead may be required for routing the PM core data package through the ground data network. If mission resources allow, much more PM data may be downlinked including selected specimen physiological data (EKGs, heart rates, etc.) from the specimens, video frames from selected cameras, and additional ECLS data. The uDACS approach supports both preset downlink data content and content determined by uplinked commands.

Our current understanding of the Payload Module science requirements, expected ground link data rates of 100K to 250K Bits per Second (BPS), and projected RRS to ground communication windows dictates the need for a mass storage capability on board the RRS in addition to the ability to downlink samples of physiological data whenever mission conditions will allow.

5.2.2 Video Downlink vs. Frame Storage and Downlink

The RRS to ground communications link will not be of sufficient bandwidth to support live video downlink. This means that an onboard video storage system must be used if images are to be transmitted to ground. This system will most likely provide some form of data compression to reduce video bandwidth and storage requirements.

5.2.3 Location of the Mass Storage Device: Inside vs. Outside the Payload Module.

The PM science requirements indicate data collection and recording capabilities for 5 channels of biological telemetry per animal (one electrocardiogram quality and four low bandwidth). This requirement alone will easily produce enough data to fill a mass storage device sized to fit in the PM (a 1 gigabit flight data recorder). An analysis of SRV (Satellite Recovery Vehicle) data system requirements presently indicates little or no need for a mass storage device. We therefore recommend that a dedicated mass storage device be located inside the PM for storage of experiment data. This will maximize the science data returned, simplify the interface between the PM and the SRV, and result in a more self-sufficient PM.

5.2.4 Commonality in the PM and SRV Microcontrollers vs. Customized Controllers for Each

As discussed in Section 5.1.3, a uDACS architecture is favored for the PM Data System. In order to maximize hardware and software commonality between the RRS Vehicle Data System and the PM Data System, we recommend that the PM use the same uDACS architecture as the RRS Vehicle. Sufficient flexibility exists within a uDACS framework to satisfy the requirements of the PM Data System. For example, one uDACS architecture may accommodate a variety of Central Processing Unit (CPU) cards, so an optimal CPU may be chosen for the PM Data System.

5.2.5 Location of PM Power Switching Relays: Inside vs. Outside the PM

It is recommended that PM power switching capability be located both inside and outside the PM. Power switching on the vehicle side would control redundant utility grade power feeds into the PM and would be used to protect the vehicle power system. Power switching inside the PM would be used to manage and protect PM equipment. All power switching would be controlled by the uDACS.

6.0 HABITAT DESIGN

The design of the habitat plays a major role in determining the validity of the science carried out in the LifeSat rodent module. The issues discussed in this section include:

- o Selection of Food Delivery System (Section 6.1)
- o Comparison of Cage Wall Designs (Section 6.2)
- o Light Source Selection (Section 6.3)
- o Number of Rodents and Duration (Section 6.4)

Module design configuration drawings and sketches have been prepared with the last section to support selection. Weight and power summaries have also been prepared.

6.1 FOOD BAR VS. PELLET

In order to verify hardware operation, and as a check on animal health, food consumption will be measured to a fairly high degree of accuracy. Three basic types of rodent feeders have been developed: 1) a RAHF-type food bar, modified for more reliable consumption measurement, 2) a pellet feeder, dispensing pellets small enough so that the rodents will consume the entire pellet and not throw half of it away, and 3) a paste diet similar to that developed at KSC.

6.1.1 Discussion

The first option is the most simple and offers the highest density for food storage. The feeder works by spring loading a large food bar (1.28 x 0.8 x 16.25 inches) against a stop. As the rodents nibble away at the end of the bar, it advances. Food consumption is measured by noting when the bar advances and by how much. Unfortunately, it is the least accurate, since the large cross-section of the bar causes it to advance very slowly on the average as the food is consumed. In actual practice, the bar does not advance at all for long periods of time as it is nibbled away, then advances all at once as the last part is consumed. In addition, integrating the bar into the spacecraft design becomes more difficult as the mission duration (and hence bar length) increases. The

16-inch bar suffices for one rat for a 9 day mission; a 60 day mission would require multiple feeders per rodent. For those reasons it is not recommended.

The KSC paste diet is certainly the most innovative of all three types; it would be dispensed out of a tube when the rodent sticks its snout into a feeding alcove and breaks a photocell circuit. Measurement accuracy is much greater than with the food bar since a small amount can be extruded at a time. Although it has been successfully demonstrated with weaning rats for a 28 day period, several problems remain with long term use. The first is microbial contamination. In its dry state, it is shelf-stable for at least 180 days; once hydrated, however, it becomes an ideal medium for microbial growth. In an under-utilized feeder (i.e., one in which the daily dispensing rate is less than the rate at which bacterial contamination can spread) the food might not last the 30 or 60 days required. There is also the problem of excessive tooth growth due to the lack of gnawing required with the soft food. This could be solved by putting an additional, non-nutritive "gnaw block" in the cage with each rodent. However, due to the aforementioned microbial contamination problems, this type of feeder is not recommended.

The pellet dispenser seems to offer the best of both worlds in that it combines high measurement accuracy (one simply counts the number of pellets dispensed) with a shelf-stable food form readily acceptable to rodents. There are many variations of the basic dispenser design, some of which have been successfully flown (e.g., the RAHF primate feeder.) It also has a high degree of commonality with the types of feeders being developed for the Space Station Modular Habitats.

6.1.2 Conclusion

It is recommended that a pellet type dispenser be used in the rodent cages. This meets the requirement for high accuracy food consumption measurement and, equally important, provides a food form that will remain microbially stable for a 60 day mission.

6.2 SOLID CAGE WALLS VS. SCREEN INNER CAGE

Two types of rodent cages have been flown on the Space Shuttle: i) the RAHF-type cage with 4 hard walls, a fine mesh screen for the "ceiling", and a open grid floor, and

2) an Animal Enclosure Module (AEM)-type of cage where all 6 walls (minus window area) were constructed of an open wire grid. Both types are being considered for LifeSat.

6.2.1 Discussion

The RAHF cage was the result of a very space-constrained design. Its primary attribute is volume efficiency. Unfortunately, it was designed with the premise (hope?) that the rodent would remain oriented such that urine would go directly into the waste tray. In actual practice, the rodents floated about without regard to orientation; the result was urine all over the walls and ceiling. When the animals came in contact with the walls they too became coated with urine. The AEM avoided this problem by separating the screen inner cage from the outer walls. Thus, most of the urine passed through the inner cage, rather than remaining on it. For the LifeSat application, it is anticipated that a chemically treated blotter will be placed in the space between the habitat wall and inner cage. This will absorb urine and prevent it from decomposing into ammonia. This should reduce the ammonia generated to 27% of the solid cage option, which in turn will reduce the amount of phosphoric acid treated charcoal by approximately 1 kg per 6 rats per 30 days.

The negative side of the wire cage option is that it adds approximately 2" to the length, 2" to the width, and 1" to the height of the habitat to accommodate the standoff space and blotter. This increases the total volume of the habitat by 30%. At this point however, the problems of waste and odor control for long periods of time appear to be more difficult than volume minimization. It is recommended therefore that the urine cage option be pursued.

6.2.2 Conclusion

The inside of the habitat should be similar in construction to the AEM, with the specimens housed in a wire screen inner cage, with a standoff distance of approximately 1/2" - 3/4" from a chemically treated blotter material.

6.3 LIGHT SOURCES

6.3.1 Discussion

The selection process for cage illumination used the major parameters of intensity and spectrum of the illuminating source, electrical conversion efficiency, weight of a logically consistent design meeting all requirements, and the ability to illuminate 12, 18, and 24 cages. Only currently available, low risk technologies were selected. The resulting five technologies and respective design candidates were evaluated on the basis of these parameters and philosophy. For all cases considered, both a redundant backup light source and feedback to insure illumination exists and is at the predetermined value is proposed.

6.3.2 Conclusions

The cold-cathode miniature fluorescent (CCF) light source was selected as most desirable for its ability to meet the requirements for all cage numbers and for its ability to have a constant power requirement for 12, 18, and 24 animal configurations. A prototype light source was constructed and tests conducted to verify the CCF light source meets all requirements. The prototype is shown in Figure 6.3-1.

The cold-cathode fluorescent light source was selected over the electro-luminescent (EL) technology on the basis of the light stability. The EL source experiences an approximate light intensity change of an estimated 8 lux over a 1440 hour mission. Furthermore, the EL sources should ideally be replaced every mission due to its half-life of 1500 hours. Since the reflectivity of the cage interior will significantly change over the mission time span, a light source which could be increased over time would provide the specimens with a more constant lighting system. The EL candidate would be hardest to provide this vernier capability.

Table 6.3-A summarizes the candidates in terms of their overall system performance. All corresponding power losses, light losses, coupling losses, and degradations have been included. In this table the cold-cathode fluorescent approach was taken as the normalizing system for comparisons of the other candidates. A second cold-cathode

fluorescent tube was included in this list in order to reflect an optionally different spectrum and bulb configuration. It should be noted that the requirement for "natural sunlight" is relaxed to include a more narrow spectrum such as 568+/- 50 nm (bright yellow). The LED approach could be considered and would represent the lowest cost approach. Each candidate light source is plotted on the CIE chromaticity diagram shown in Figure 6.3-2 for comparison. As can be seen in this figure, all sources selected, except for the LED, are very similar in chromaticity.

In summary, the advantages in selecting the CCF option are as follows:

A. Scientific

- o Meets all requirements
- o Useable for up to 8 missions
- o Lowest cost (design + parts)
- o Lowest power consumption and lowest weight
- o Adjustable spectra (different bulbs are available).
- o Closest spectrum to daylight
- o High MTBF

B. Programmatic

- o Off-the-shelf technology
- o Lowest development engineering
- o Lights in stock; multiple suppliers

C. Scientific Payload Flexibilities

- o Intensity can be varied (0 to 75 Lux)
- o Spectrum selectable - fixed options
- o Very diffuse lighting - no point sources.

D. Technology Risk Assessment

- o All components are off-the-shelf
- o All components proven
- o Prototype currently exists
- o Housing for 18 and 24 rats needs to be designed

E. Programmatic & Cost Risk Assessment

- o Current prototype (see Figure 6.3-1) minimizes program/cost risk

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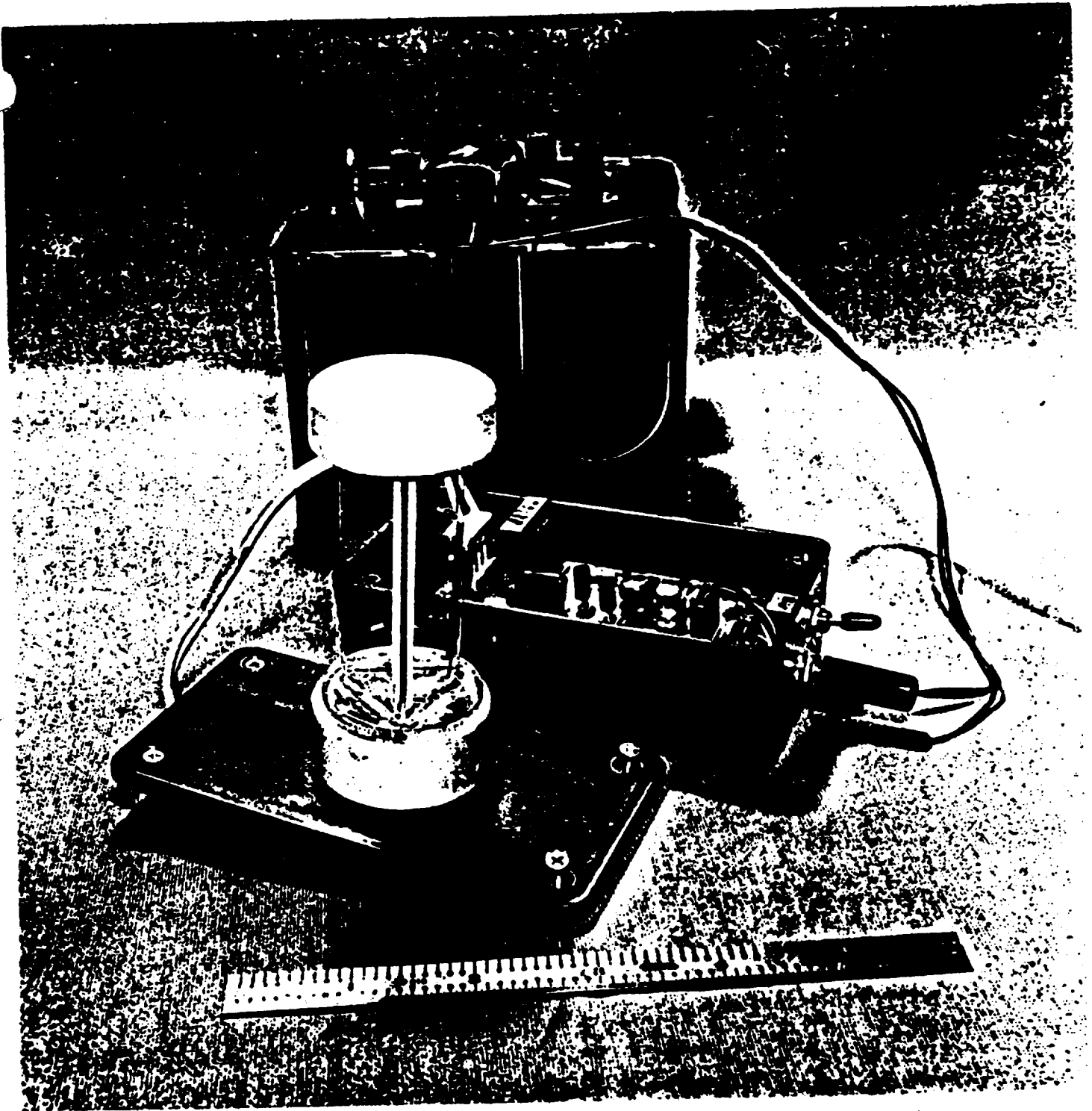


Figure 6.3-1 Prototype Cold-Cathode Fluorescent (CCF) Light Source

Table 6.3-A Normalized Candidate Comparisons

(Taking the cold-cathode fluorescent light source as the baseline.)

| RATIOS (Candidate-to-CCF) | | | | | | | | | | | |
|---|------|------|------|------|------|-------|-----|-----|--------|------|------|
| CANDIDATE TECHNOLOGY | LIFE | COST | | | LITE | POWER | | | WEIGHT | | |
| | | 6/12 | 18 | 24 | | 6/12 | 18 | 24 | 6/12 | 18 | 24 |
| <u>Cold-Cathode Fluorescent (CCF)</u> (Model HMB4[NWE]50B: 5060°K) | 1.0 | 1.00 | 1.00 | 1.00 | 1.00 | 1.0 | 1.0 | 1.0 | 1.00 | 1.00 | 1.00 |
| <u>Focused Lens-End Gas Lamp</u> (Model L1024A, 2490°K: 5060°K) | 0.3 | 1.01 | 1.02 | 1.03 | 0.63 | 4.1 | 4.1 | 6.1 | 0.70 | 1.20 | 1.40 |
| <u>Electro-luminescent</u> (Model: BKL-Cool White: [0.026,0.36]) | 1.0 | 0.62 | 0.64 | 0.66 | 0.34 | 3.1 | 4.1 | 4.9 | 0.70 | 0.90 | 1.08 |
| <u>Cold-Cathode Fluorescent</u> (Model HMB4[DWE]54/48/P: 6500°K) | 1.0 | 1.05 | 1.06 | 1.08 | 1.00 | 2.8 | 2.8 | 2.8 | 1.03 | 1.07 | 1.11 |
| <u>LED</u> (Model GL5PY44, Lemon-yellow: 568 nm) | 20 | 0.73 | 0.79 | 0.85 | 1.00 | 1.5 | 2.0 | 2.9 | 0.66 | 0.95 | 1.23 |

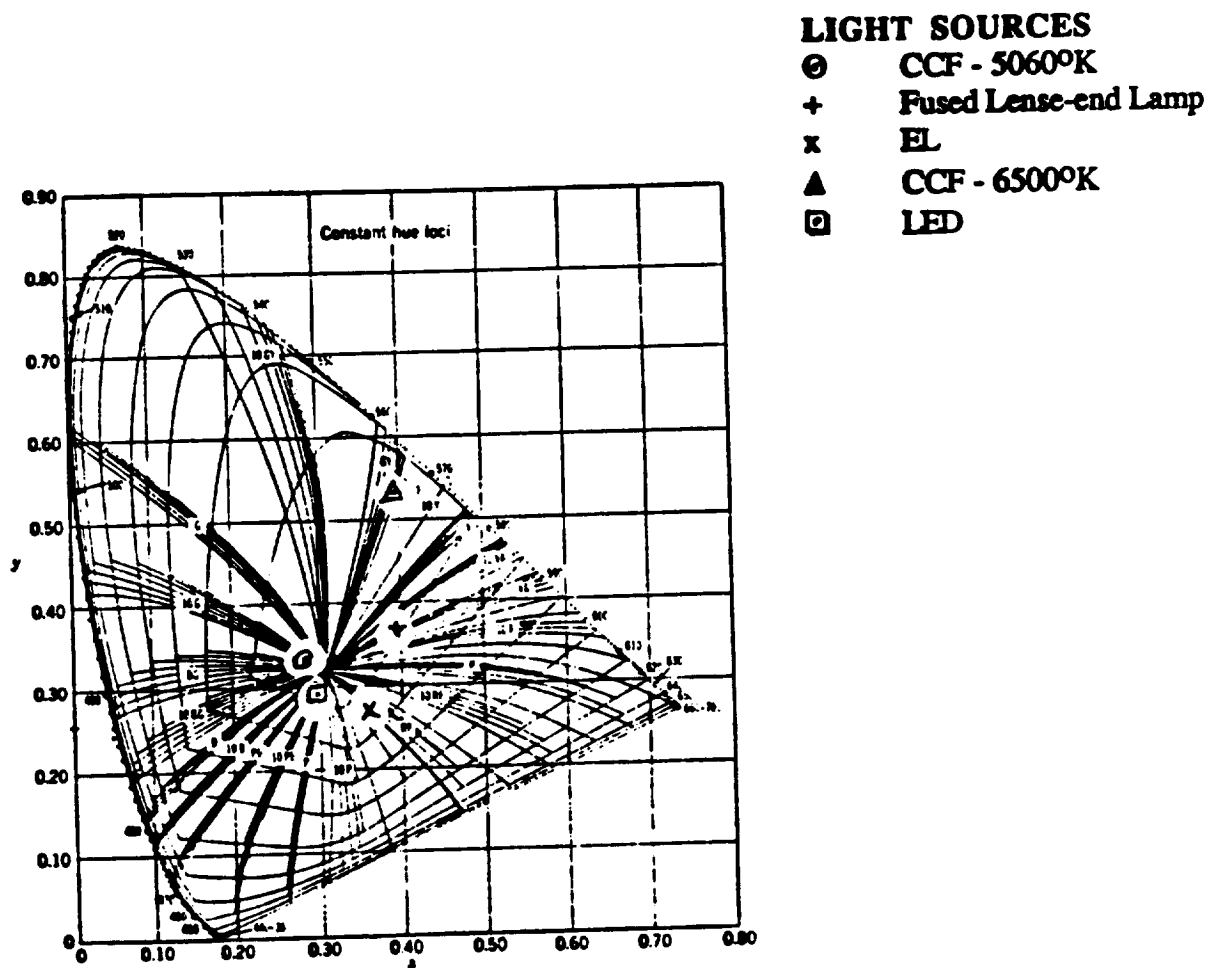


Figure 6.3-2 Loci of Munsel Hues on CIE Chromaticity Diagram

6.4 NUMBER OF RODENTS AND DURATION

Based upon the data generated in the foregoing sections and interface discussions with GE, a number of possible configurations having rodent capabilities of from 6 to 24 animals and from 24 to 60 days mission duration were selected for evaluation. The configurations evaluated and notes on the extent of evaluation are presented Table 6.4-A.

The power consumption of the system is of critical importance since battery weight is a major factor in vehicle weight. The minimum power approach is that of the sorbent carbon dioxide and water removal. Table 6.4-B presents the power and battery capacity data requirements for the rodent module.

Figures 6.4-1 through 6.4-13 show configurations of the rodent module which were investigated in support of the study. A brief description of each of these figures follows.

6.4.1 Figure Descriptions

Figure 6.4-1 is an overall representation of the LifeSat vehicle. The LMSC effort is focused on the payload envelope and interfaces with the remainder of the vehicle. The studies presented in this report are for the equipment within the envelope. The following presents information on the packaging of the equipment within the payload envelope.

Figure 6.4-2 is an early representation of a 12 rodent/24 day mission payload module based upon the RAHF (Research Animal Holding Facility) individual cage modules. The figure shows packaging of the module within the vehicle and illustrates access and placement of the ECLS, data, and power system components.

Extending the research capabilities to group-housed animals resulted in a cage configuration such as the one shown in Figure 6.4-3. This configuration provides for 6 animals either in a common habitat or separated by partitions inserted for the specific mission. The food, water, and data sections are at the top of the module. Waste management is provided in the floor. Air is recirculated by the fan located in the wedge section of the cage. The air, which is particulate and activated carbon filtered

after leaving the waste management section, enters the cage module at the top where the utilities are located. Thus a method is provided, through air flow, to keep the food and data services as clean as possible.

Figure 6.4-4 shows an implementation of this cage module in the payload module. The ECLS is shown nestled in the area above the cage recirculation fans. Water and gas tankage is shown at either side of the two cage modules. Figure 6.4-5 is a similar layout but with the recirculation fan and ECLSS located at the bottom to provide improved access to the module for late access. Both of these layouts have sufficient volume to accommodate 60-day mission expendable requirements.

In an attempt to minimize the diameter of the module to use smaller launch vehicles, the layout presented in Figure 6.4-6 was developed. It shows tankage located outside the pressurized module to conserve volume. The cages are located around the outside of the module in a racetrack configuration. This unit has a diameter of only 39 inches and can provide for 12 animals for up to 60 days if the volume for external expendable stores is available. Figure 6.4-7 is an alternate racetrack configuration with all storage within the pressurized module.

If the top of the payload module can be contoured to the shape of the vehicle nose cone, the configuration shown in Figure 6.4-8 provides the minimum diameter. This configuration can be spun around the radial axis with the cage floor on the outside wall or operated in a spin in the x axis with the cage wall on the bottom of the module. Figure 6.4-9 shows versions of this configuration for 12 animals of 24 animals with a two story cage configuration. The 24 animal version two story unit is restricted to z axis spin for artificial gravity. The larger diameter unit (40 inches) can provide for 24 animals if a z-only spin axis is considered.

The sketches presented in Figures 6.4-10, 6.4-11, and 6.4-12 were prepared to illustrate the feasibility of accommodating varying numbers of animals. These sketches are based upon the more detailed layouts presented. Figure 6.4-10 shows 12 animals in two groups of 3 animal wide by 2 high units. The payload diameter is 44 inches by 38 inches high. Figure 6.4-11 shows a 4 wide by 3 high package for 24 animals. This configuration requires a diameter of 54 inches by 44 inches high. Figure 6.4-12 is a 3 by 3 cage module with 2 modules for a total of 18 rodents. The size is 48 inches

diameter by 40 inches high. To complete the animal number investigations, Figure 6.4-13 shows packaging within a 40 inch diameter by 25 inch high unit.

:

| INDEX | CONFIGURATION (Rate, Days) | SPIN AXIS | DIAMETER (Inches) | LENGTH (Inches) | DESIGN STATUS NOTES |
|-------|-------------------------------|--------------|----------------------|--------------------|------------------------|
| 1 | 6, 24 | Z | 40 | 28 | 1, 2, 4, 6, 8 |
| 2 | 6, 30 | Z | 40 | 28 | 1, 2, 4, 6, 8 |
| 3 | 6, 60 | Z | 40 | 28 | 1, 2, 4, 6, 8 |
| 4 | 12, 24 | Z | 44 | 38 | 1, 2, 3, 4, 6 |
| 5 | 12, 30 | Z | 44 | 38 | 1, 2, 3, 4, 6 |
| 6 | 12, 30 | X | 44 | 38 | 1, 2, 3, 4, 6 |
| 7 | 18, 24 | Z | 48 | 40 | 1, 2, 3, 4, 6 |
| 8 | 18, 30 | Z | 48 | 40 | 1, 2, 3, 4, 6 |
| 9 | 18, 60 | Z | 48 | 40 | 1, 2, 3, 4, 6 |
| 10 | 24, 24 | Z | 54 | 44 | 1, 2, 3, 4, 6 |
| 11 | 24, 30 | Z | 54 | 44 | 1, 2, 3, 4, 6 |
| 12 | 24, 60 | Z | 54 | 44 | 1, 2, 3, 4, 6 |
| 13 | 12, 30 | Z | 34 | 45 | 2, 4, 5, 6 |
| 14 | 12, 30 | X | 34 | 45 | 2, 4, 5, 6 |
| 15 | 12, 60 | Z | 34 | 60 | 2, 4, 5, 6 |
| 16 | 12, 60 | X | 34 | 60 | 2, 4, 5, 6 |
| 17 | 12, 30 | Z | 39 | 16 | 1, 2, 3, 4, 6, 7, 8 |
| 18 | 12, 60 | Z | 39 | 16 | 1, 2, 3, 4, 6, 7, 8 |

NOTES:

- (1) Full mass properties available for launch & reentry conditions: CG, First Moments, Second Moments.
- (2) Estimated power consumption available for 6, 12, 18, and 24 rate over missions of 30 and 60 days.
- (3) Catia-3 solid modeling available.
- (4) Life support expendables calculated for each configuration.
- (5) Miscellaneous configurations investigated: Tumbling, two-tier, and Pegasus.
- (6) Lighting trade study completed, cold-cathode fluorescent was selected.
- (7) External oxygen and nitrogen tanks proposed in this design concept.
- (8) This configuration is capable of having an X-axis spin.

Table 6.4-A Status Summary for LifeSat Configurations Traded

| ITEM | COMPONENT | LOCATION | QUANTITY NEEDED FOR A RAT MISSION | DUTY CYCLE % | 6 RATS PEAK POWER (watts) | 12 RATS PEAK POWER (watts) | 18 RATS PEAK POWER (watts) | 24 RATS PEAK POWER (watts) | 6 RATS AVE POWER (watts) | 12 RATS AVE POWER (watts) | 18 RATS AVE POWER (watts) | 24 RATS AVE POWER (watts) |
|------|------------------------------------|----------|--|--------------------|------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-----------------------------------|------------------------------------|------------------------------------|------------------------------------|
| 1 | ECLSS FAN (Atmos Purification Fan) | ECLSS | 1 | 100.00 | 4.31 | 7.00 | 9.30 | 11.37 | 4.31 | 7.00 | 9.30 | 11.37 |
| 2 | RECIRCULATION FANS (1 per Hub) | ECLSS | 2 | 100.00 | 4.00 | 8.00 | 12.00 | 16.00 | 4.00 | 8.00 | 12.00 | 16.00 |
| 3 | HUMIDITY SENSORS | ECLSS | 1 | 100.00 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 |
| 4 | O2 SENSORS | ECLSS | 1 | 100.00 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 |
| 5 | PRESSURE SENSORS | ECLSS | 1 | 0.10 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| 6 | LATCH SOL VALVES (Temp/O2/CO2) | ECLSS | 7 | 0.10 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 |
| 7 | LATCH SOL VALVES (O2/AZ) | ECLSS | 4 | 0.10 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 |
| 8 | LIGHTING (Ref/CCF) | HABITATS | 1-by-6 | 50.00 | 3.00 | 3.00 | 6.00 | 6.00 | 3.00 | 3.00 | 6.00 | 6.00 |
| 9 | FEEDERS | HABITATS | 6 | 0.10 | 4.98 | 9.96 | 14.94 | 19.92 | 4.98 | 9.96 | 14.94 | 19.92 |
| 10 | WATERERS (Valves) * | HABITATS | 6 | 0.10 | 3.00 | 3.00 | 6.00 | 6.00 | 3.00 | 3.00 | 6.00 | 6.00 |
| 11 | VIDEO CAMERA SYSTEM | MODULE | 1 | 1.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| 12 | BIOTELEMETRY RECEIVERS | MODULE | 6 | 100.00 | 0.08 | 0.16 | 0.24 | 0.32 | 0.08 | 0.16 | 0.24 | 0.32 |
| 13 | CONTROLLER & ELECTRONICS | MODULE | 1 | 100.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| | DATA RECORDER | MODULE | 1 | 5.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 |

| | | | | | | | |
|-----------------------|--|--|--|-------|-------|-------|-------|
| TOTAL WATTS = | | | | 13.61 | 28.39 | 28.28 | 34.43 |
| kwhr/30 Day Mission = | | | | 9.36 | 14.68 | 20.36 | 24.80 |
| kwhr/90 Day Mission = | | | | 19.60 | 29.37 | 46.72 | 49.59 |

* Place Holder for Water Metering

Table 6.4-B LifeSat Power Requirements per Mission

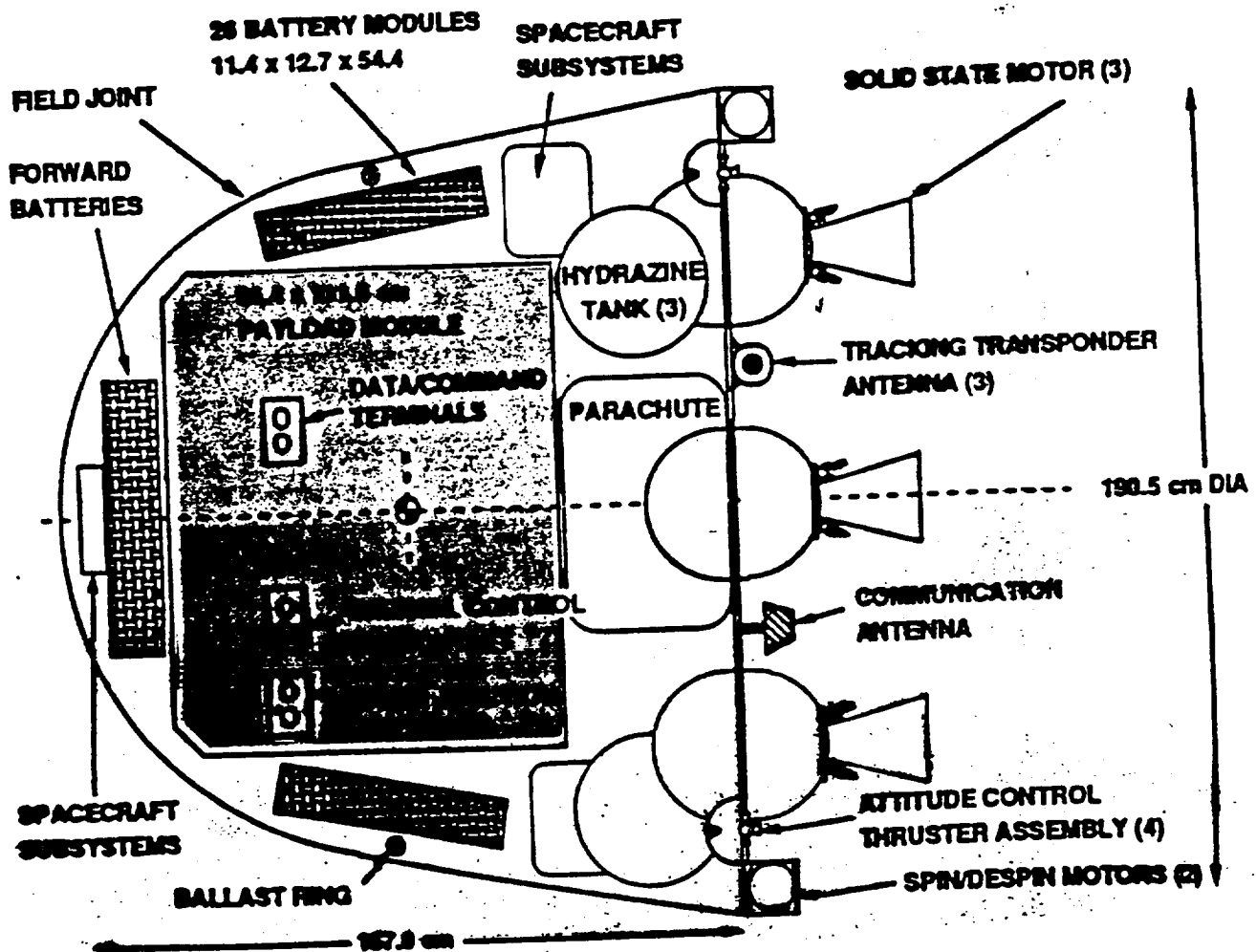


Figure 6.4-1 LifeSat Vehicle Layout

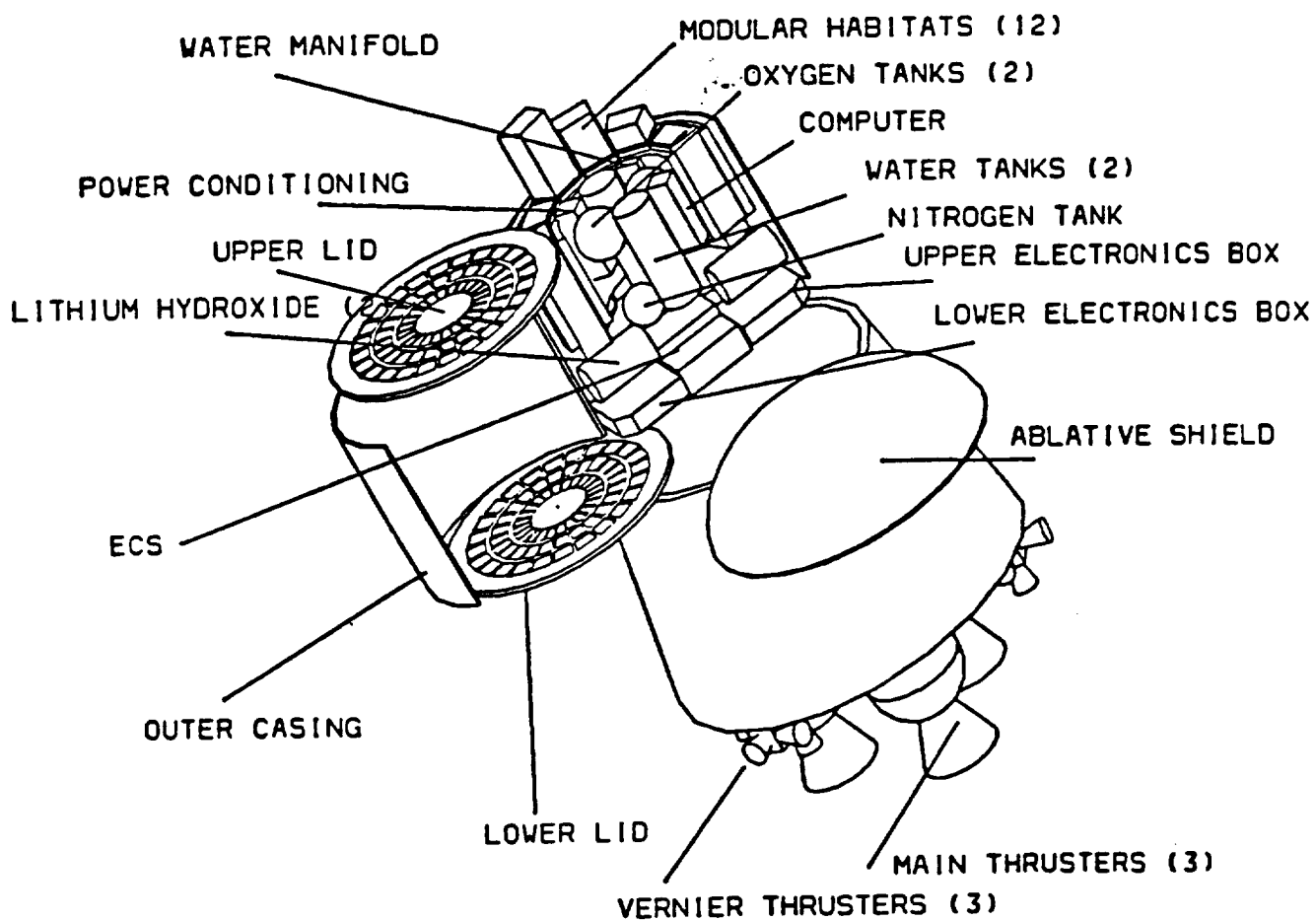


Figure 6.4-2 Layout Based Upon RAHF Cage Design

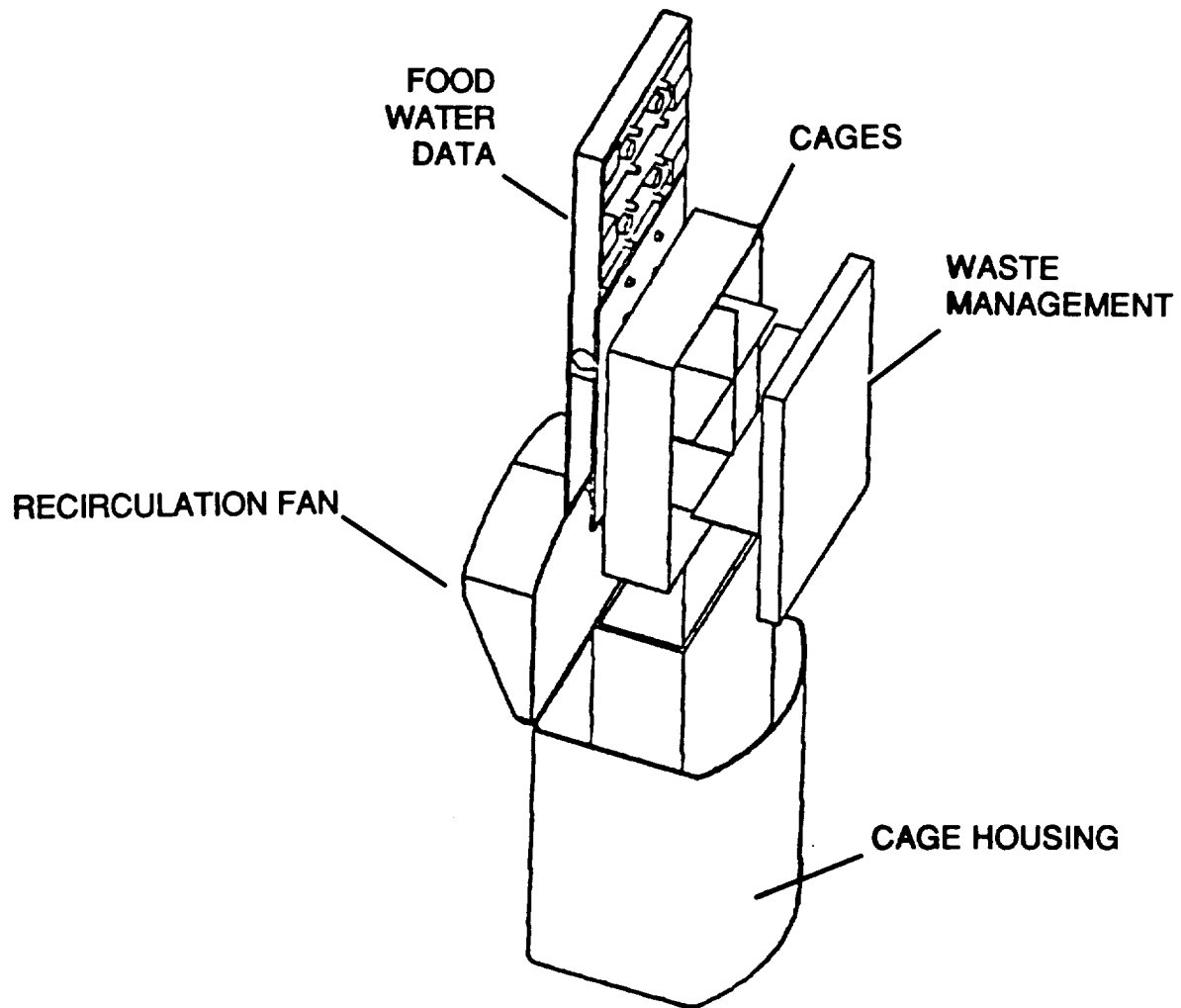


Figure 6.4-3 Typical Cage Layout (6 Animals)

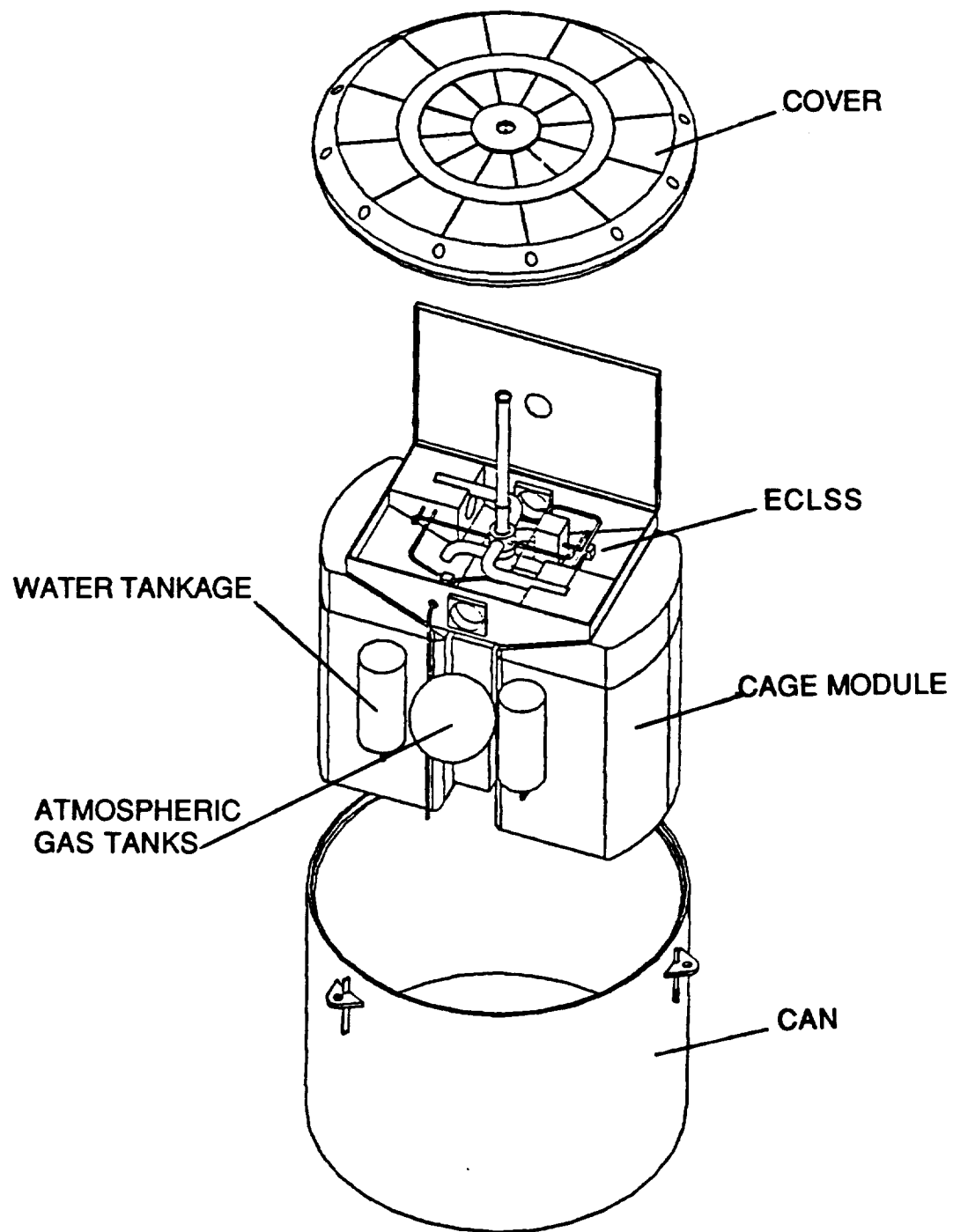


Figure 6.4-4 12-Animal Module Assembly

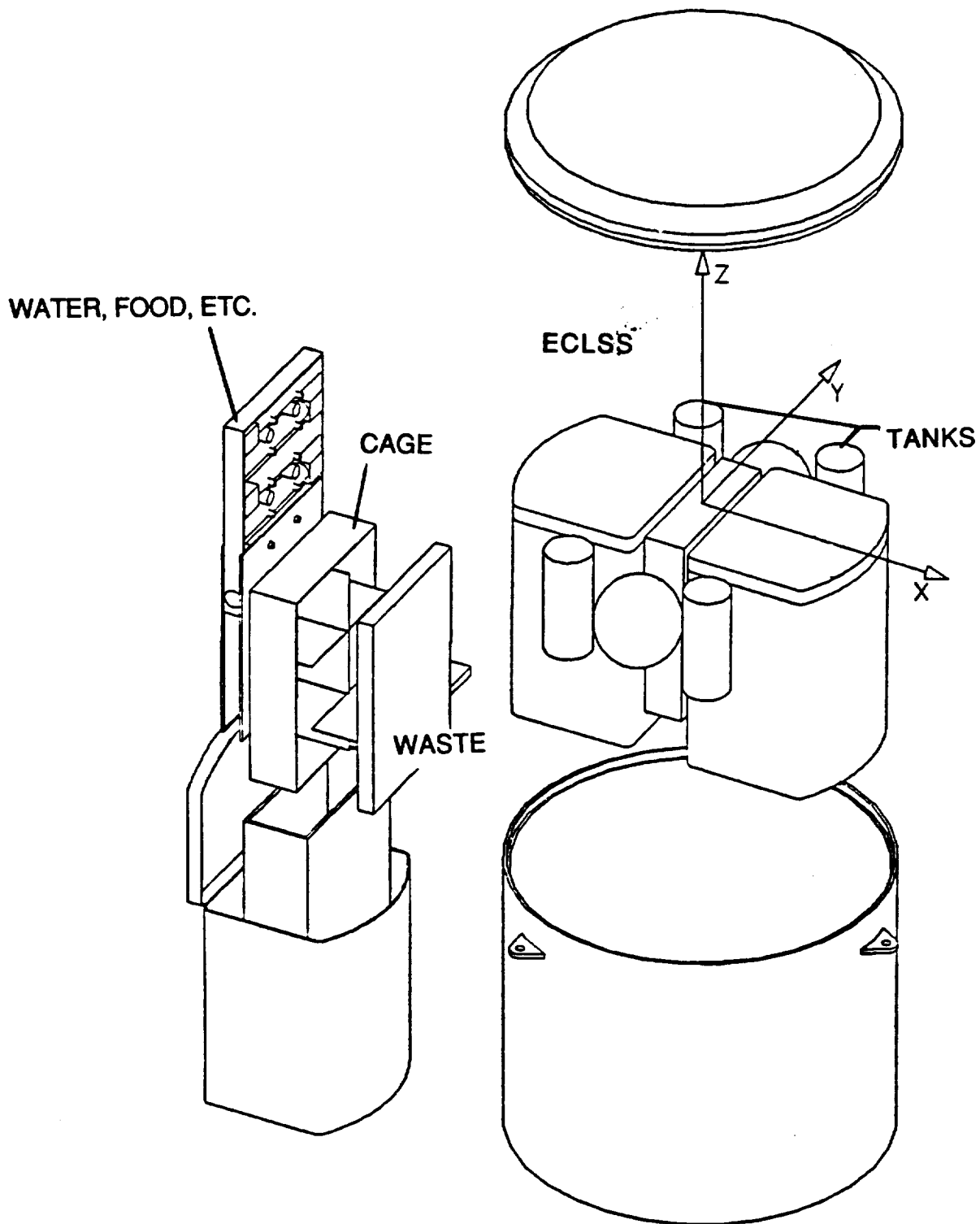


Figure 6.4-5 Alternate Design for Improved Late Access

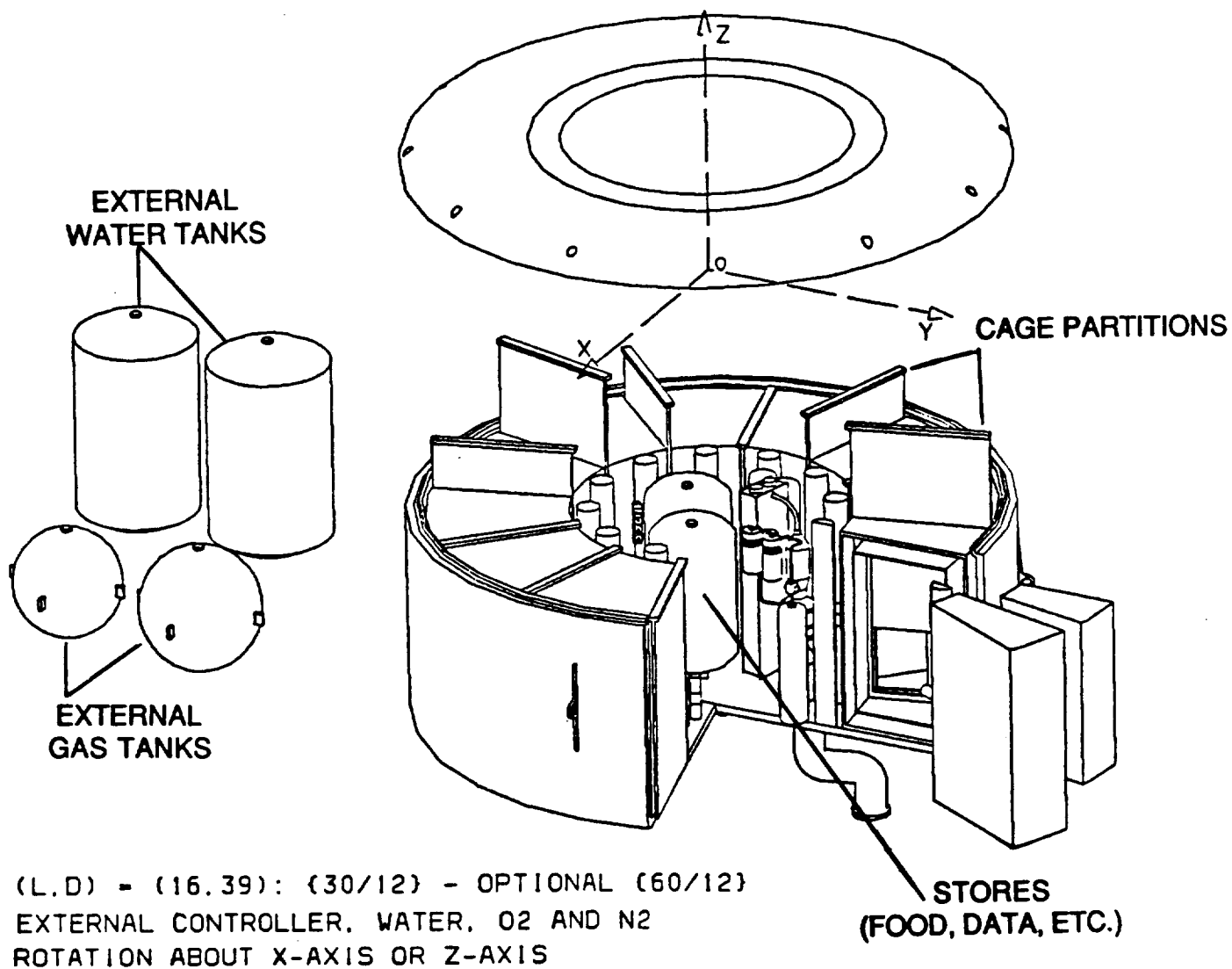


Figure 6.4-6 Minimum Diameter Design (External Storage of Expendables)

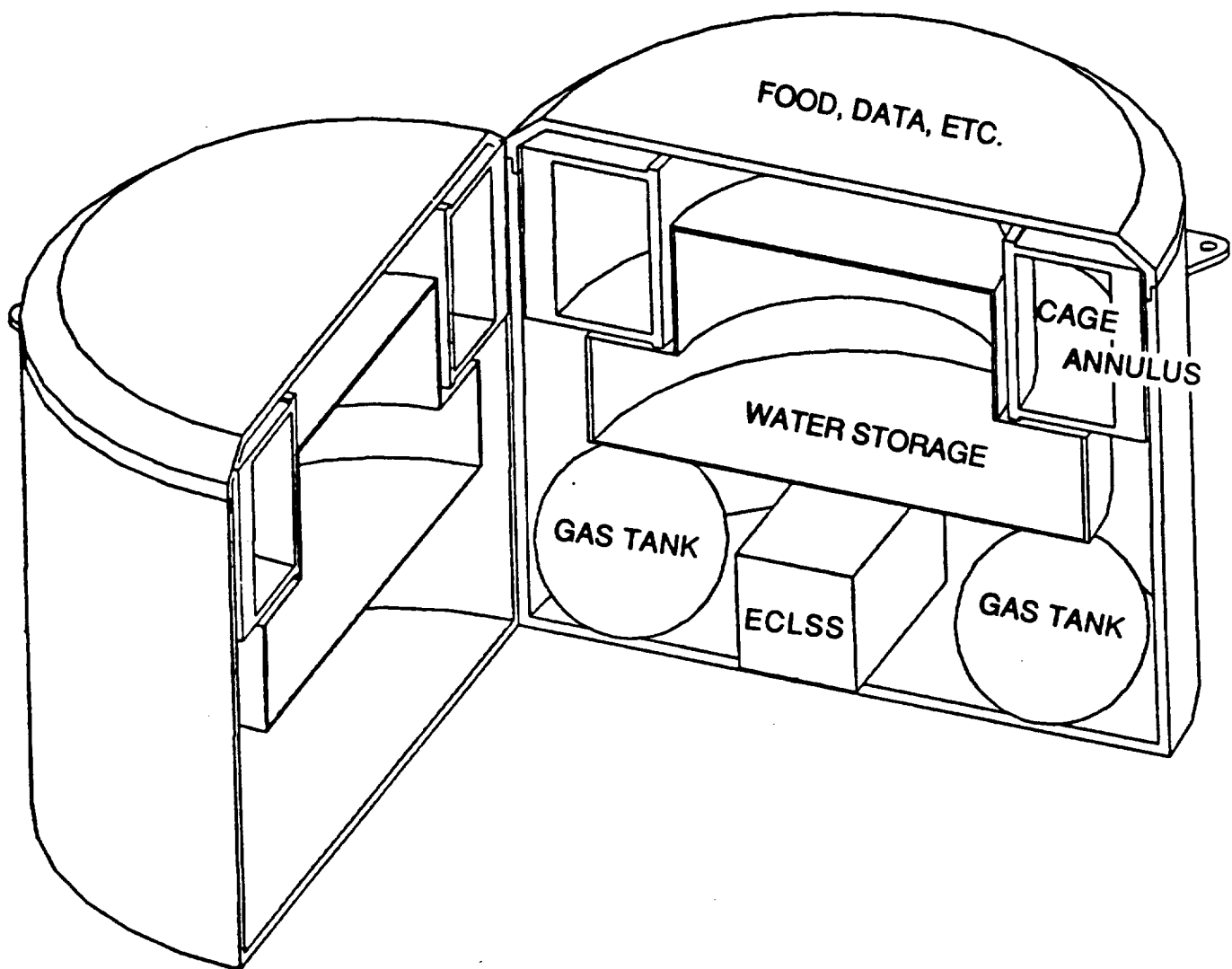


Figure 6.4-7 Alternate Racetrack Configuration (Internal Storage of Expendables)

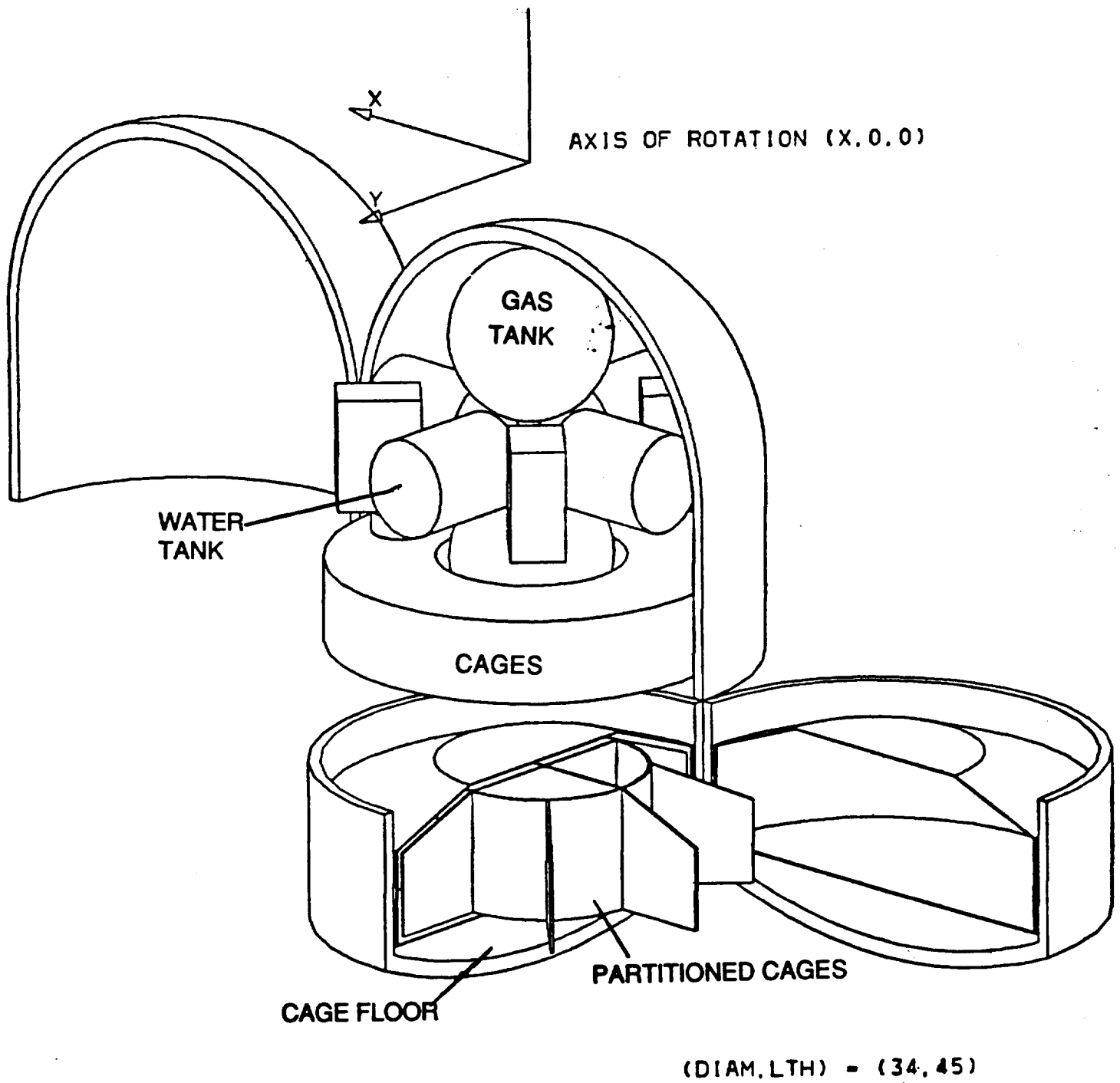


Figure 6.4-8 Configuration Shaped to Vehicle Reentry Shield Contour

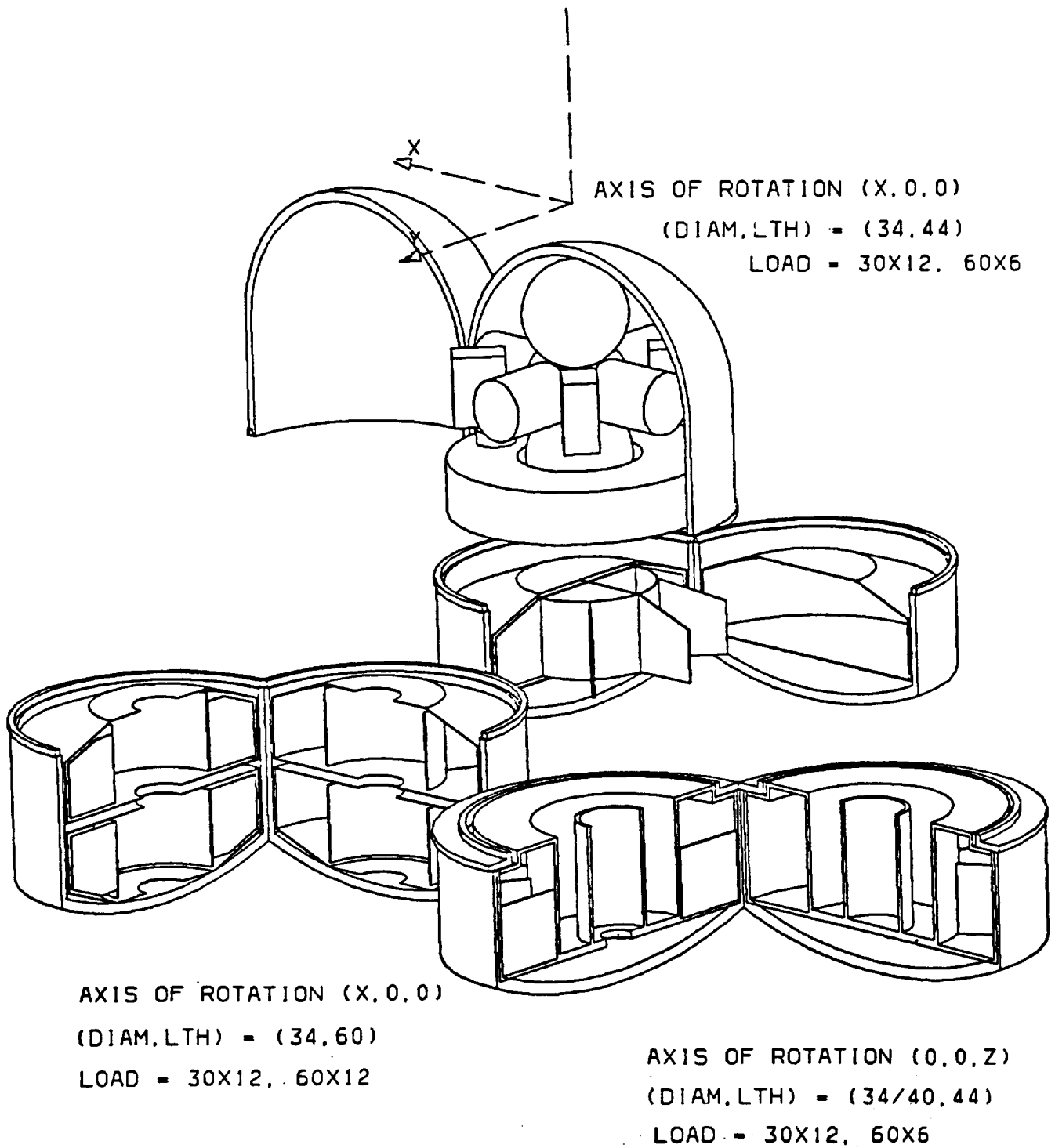


Figure 6.4-9 Alternate Cage Layouts for Figure 6.4-8 Configuration

12 RATS, 20/60 DAYS, 44" D/38" HIGH, 3' BUREAU AND LINKS

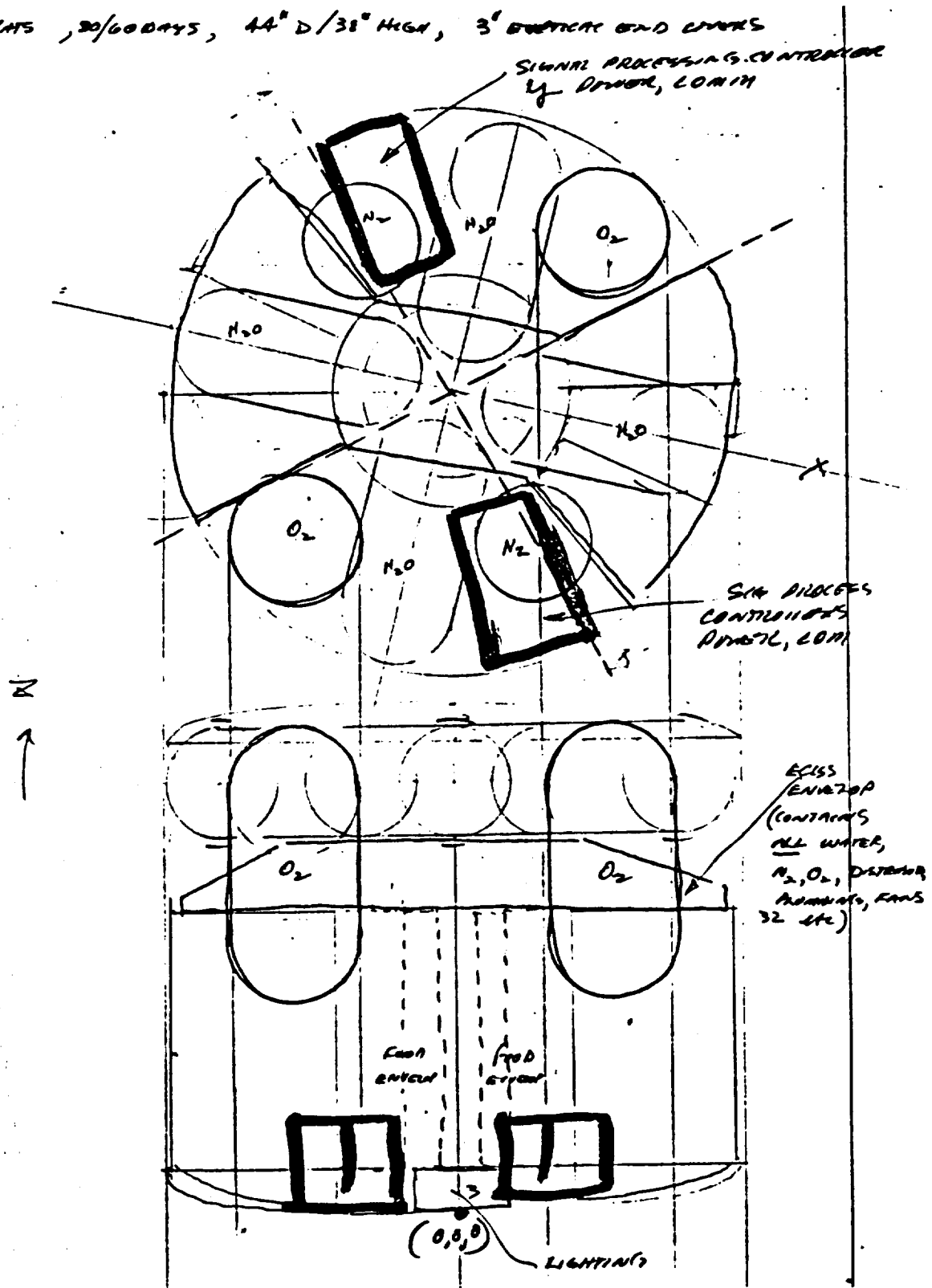


Figure 6.4-10 Recommended 12-Rat Configuration

24 RATS, 30/600ms, 34" DIAM/44" HIGH, 8" EXHAUST TUBE

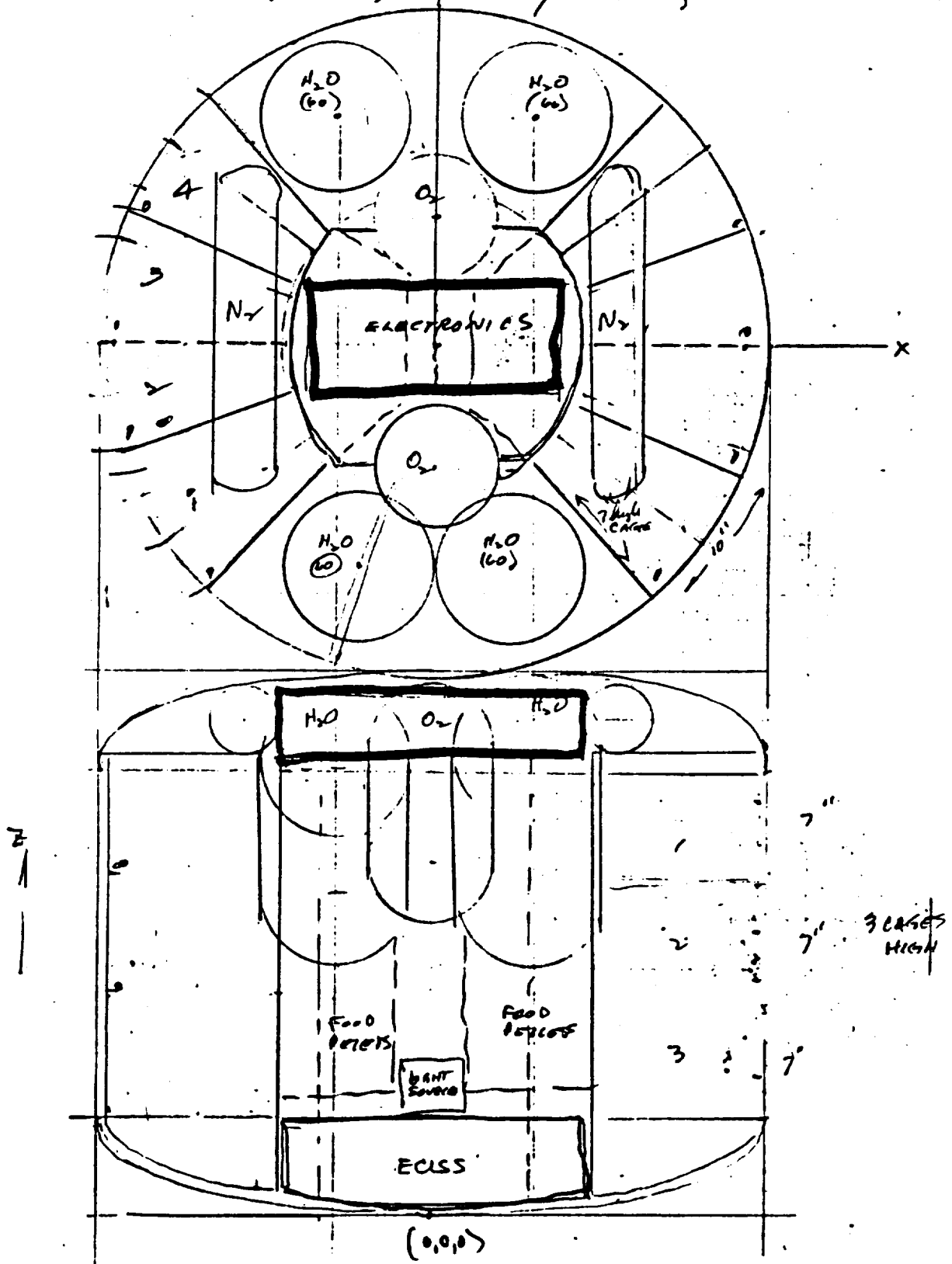


Figure 6.4-11 Recommended 24-Rat Configuration

GRATS 30/60 OR 45 40" DIAM 25" HIGH

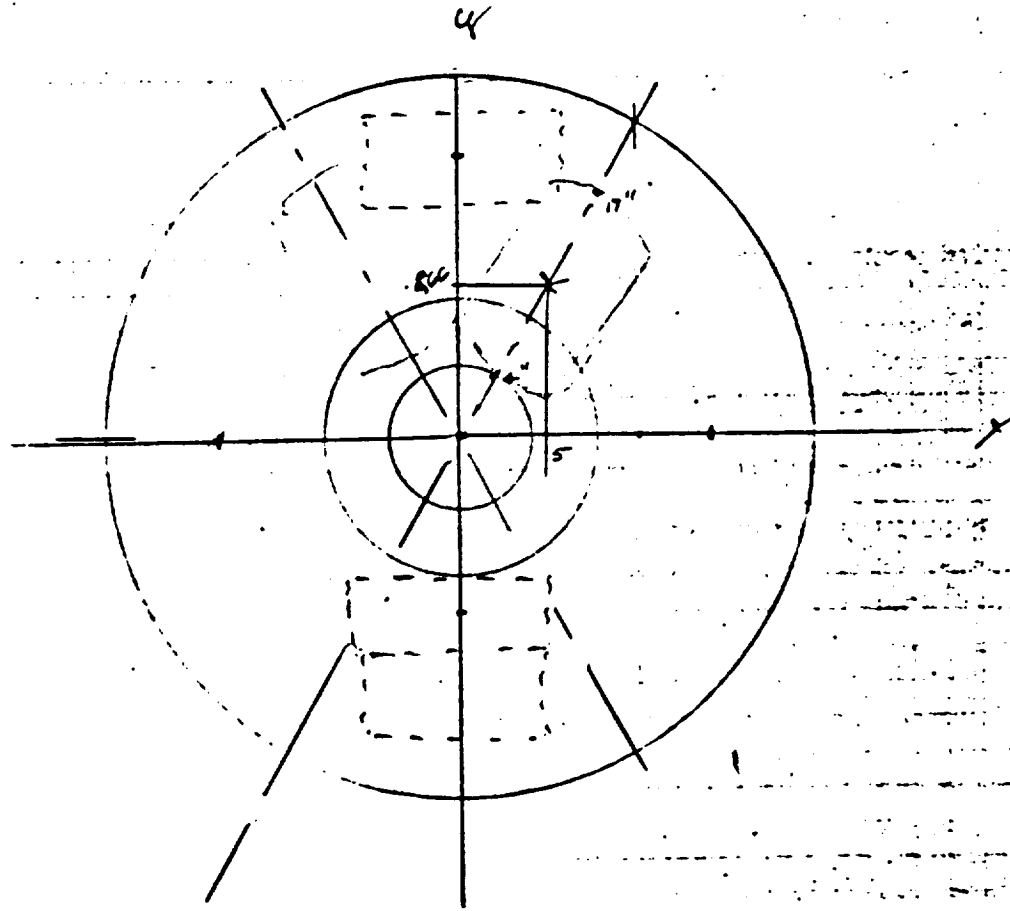


Figure 6.4-12 Recommended 6-Rat Configuration

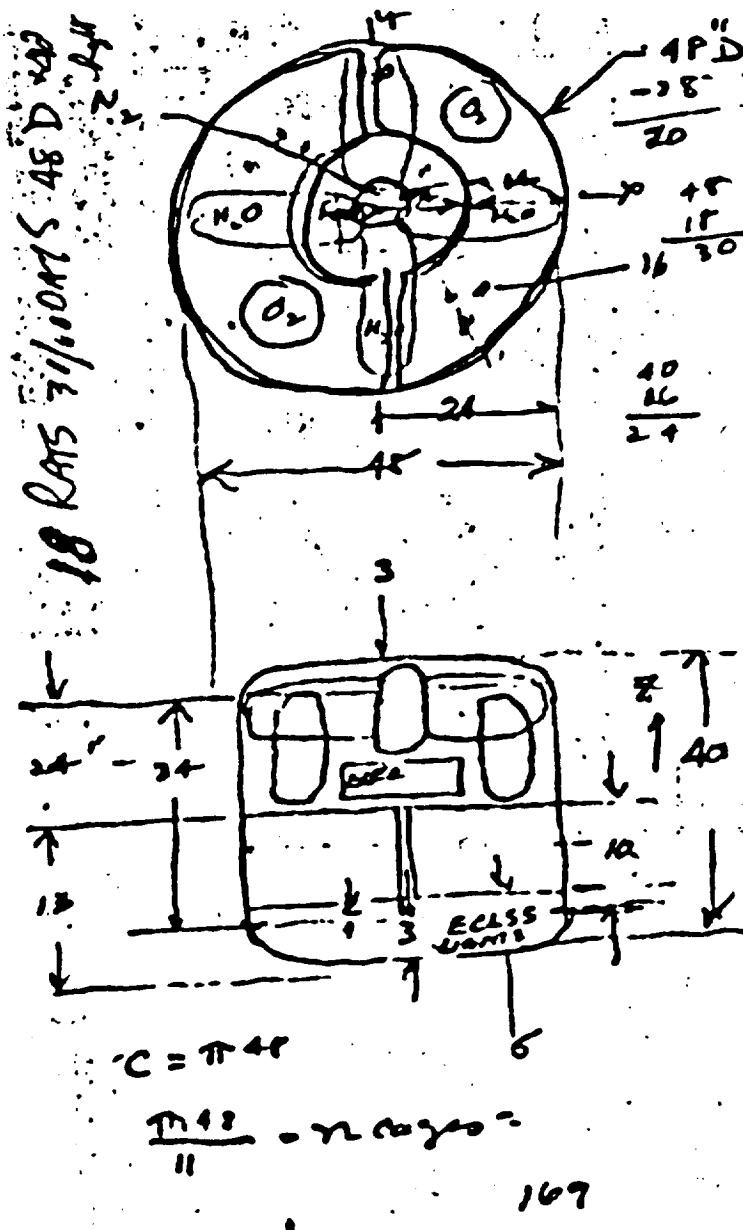


Figure 6.4-13 Recommended 18-Rat Configuration

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This report is comprised of contributions from the following individuals:

| | |
|--------------|---------------------------|
| M. Avery | Program Leader |
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| D. Mendez | Module Configuration |
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| R. Stempson | System Engineer |

